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(54) **POWER MANAGEMENT FOR REMOTE
ANTENNA UNITS IN DISTRIBUTED
ANTENNA SYSTEMS**

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See application file for complete search history.

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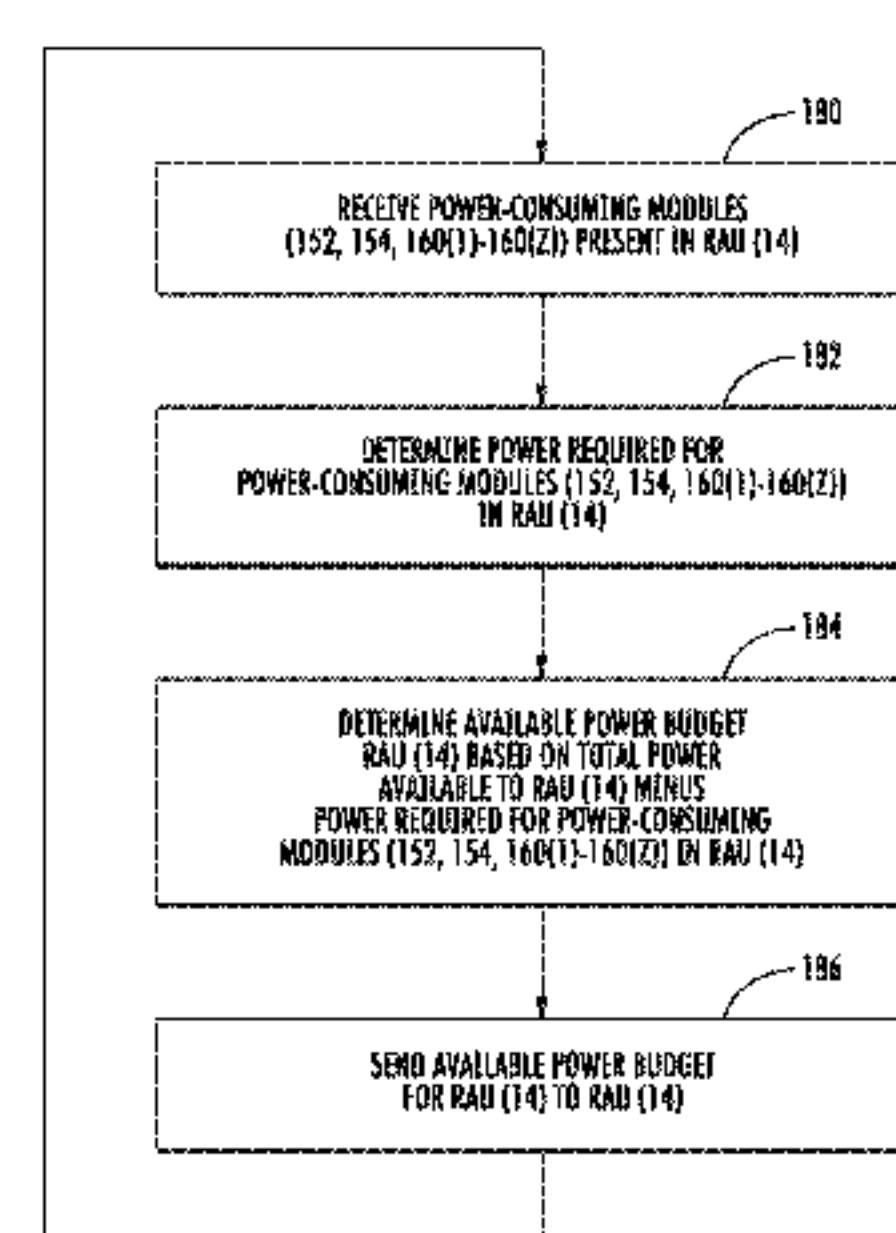
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(57) **ABSTRACT**

Power management for a remote antenna unit(s) (RAUs) in a
distributed antenna system. Power can be managed for an
RAU configured to power modules and devices that may
require more power to operate than power available to the
RAU. For example, the RAU may be configured to include
power-consuming RAU modules to provide distributed
antenna system-related services. As another example, the
RAU may be configured to provide power through powered
ports in the RAU to external power-consuming devices.
Depending on the configuration of the RAU, the power-con-
suming RAU modules and/or external power-consuming
devices may demand more power than is available at the
RAU. In this instance, the power available at the RAU can be
distributed to the power-consuming modules and devices
based on the priority of services desired to be provided by the
RAU.

13 Claims, 13 Drawing Sheets



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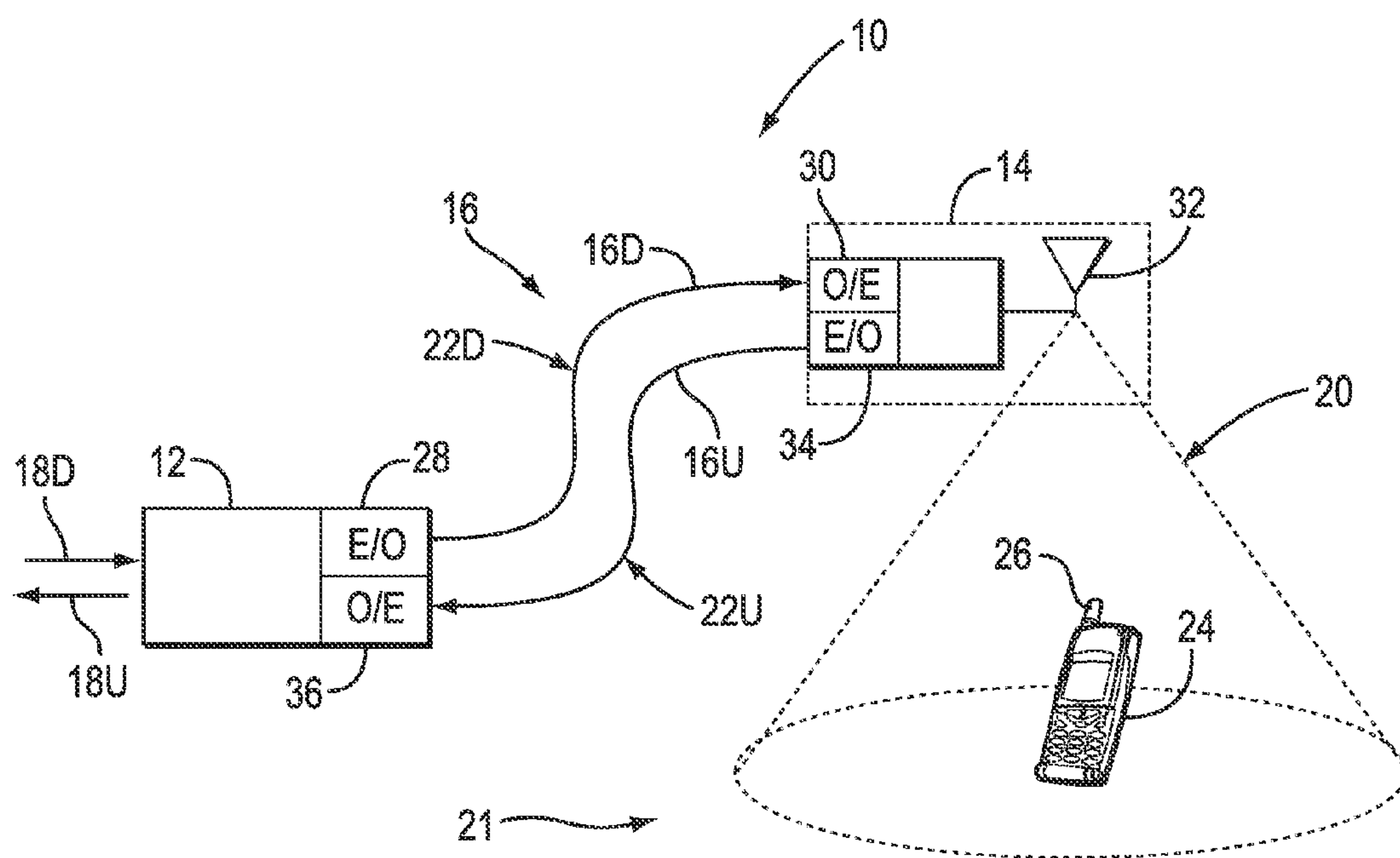


FIG. 1

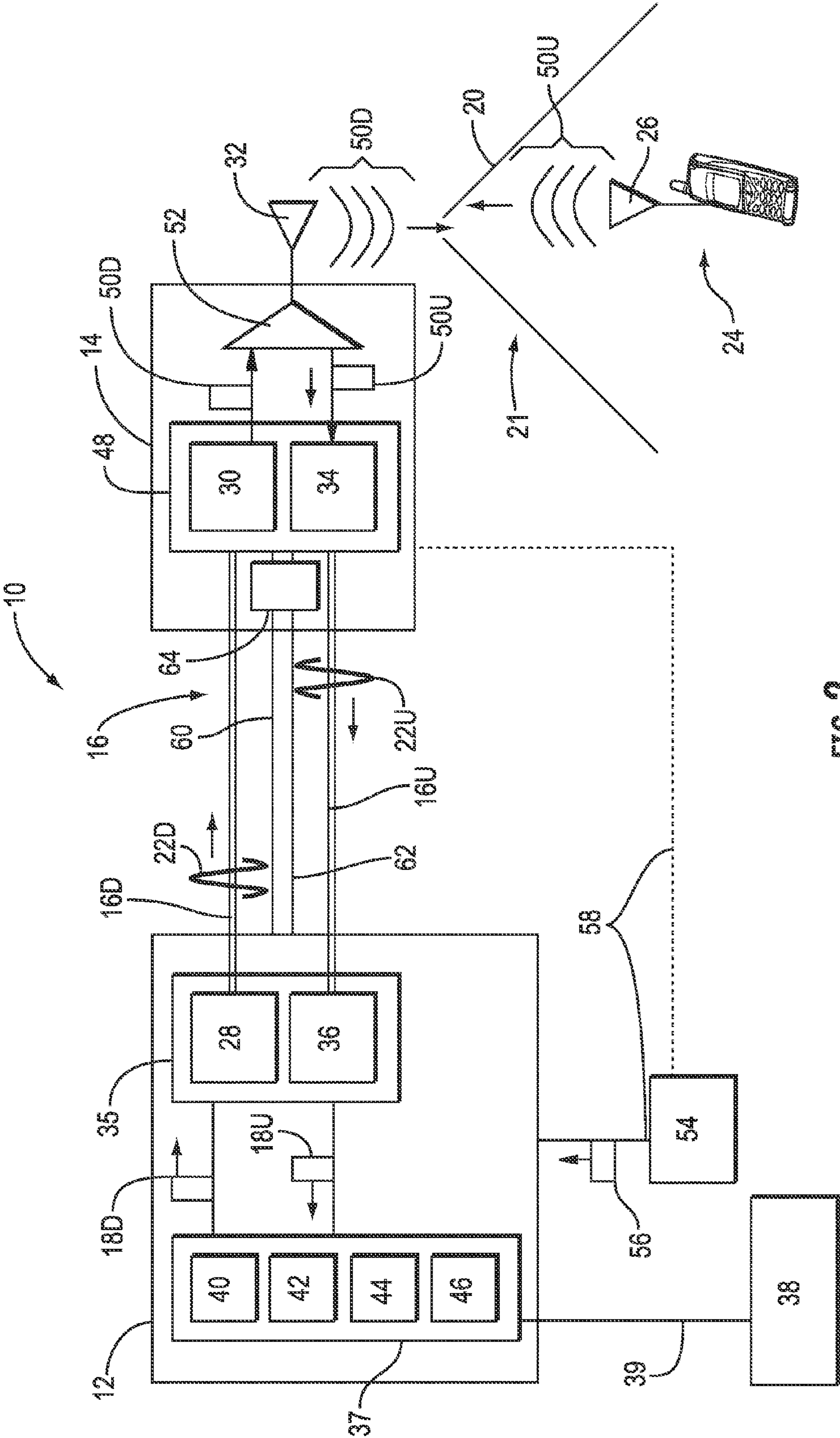
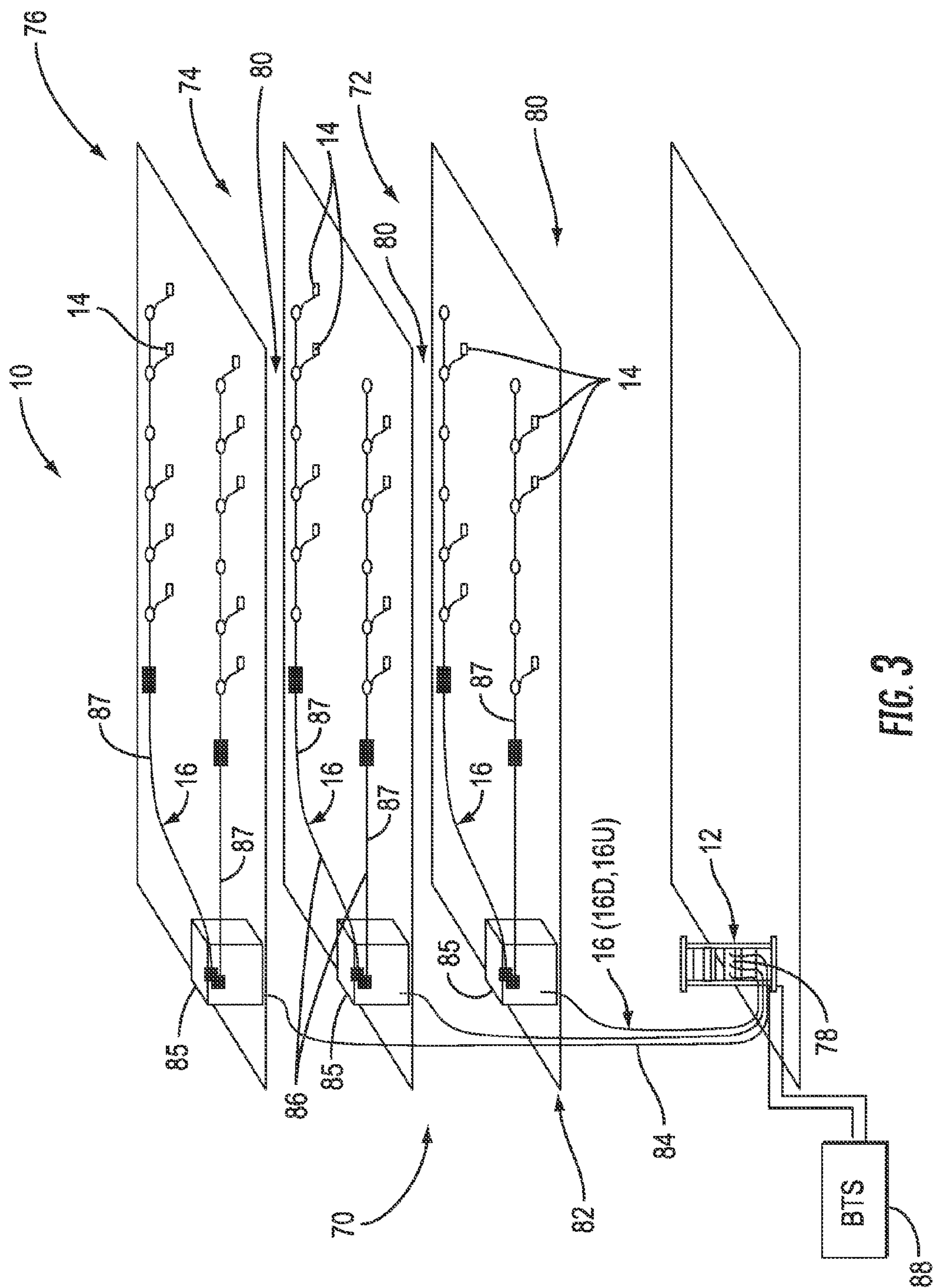


FIG. 2



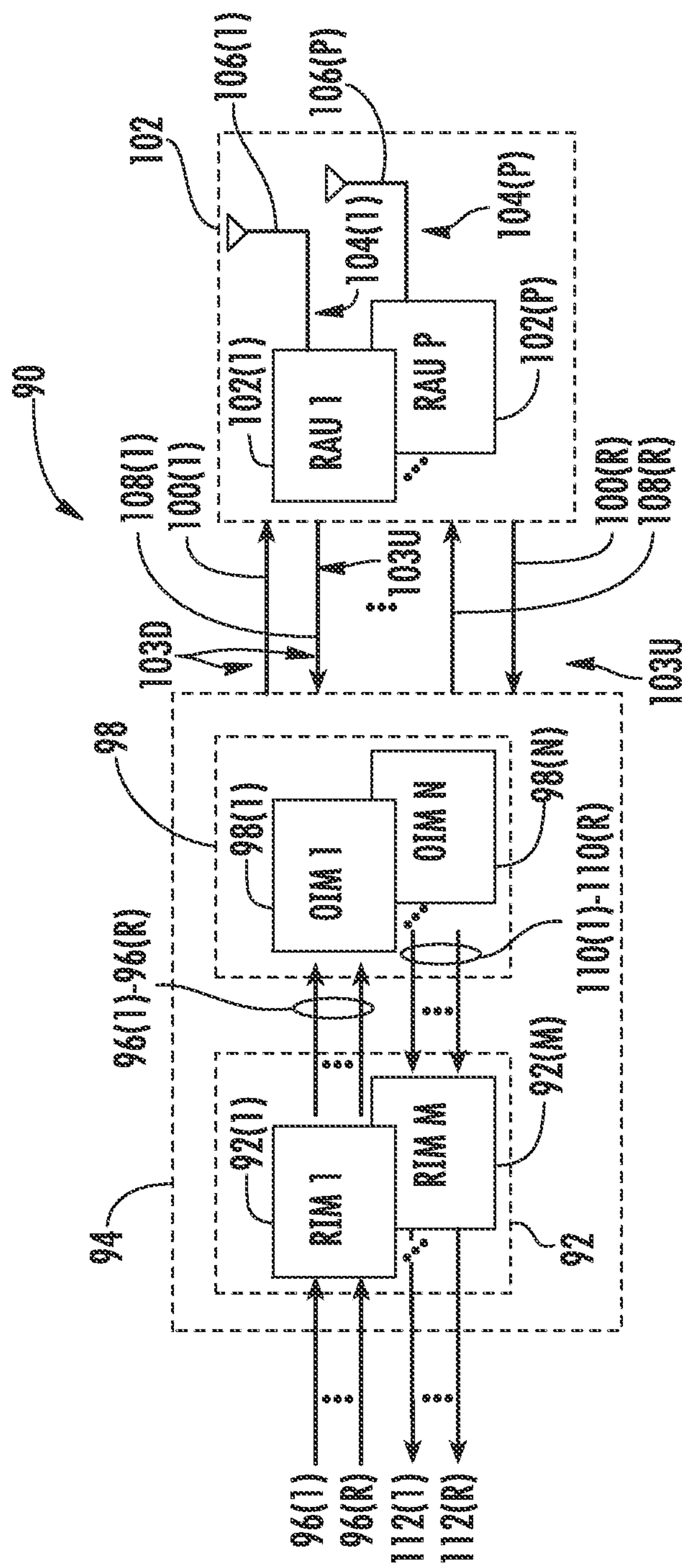
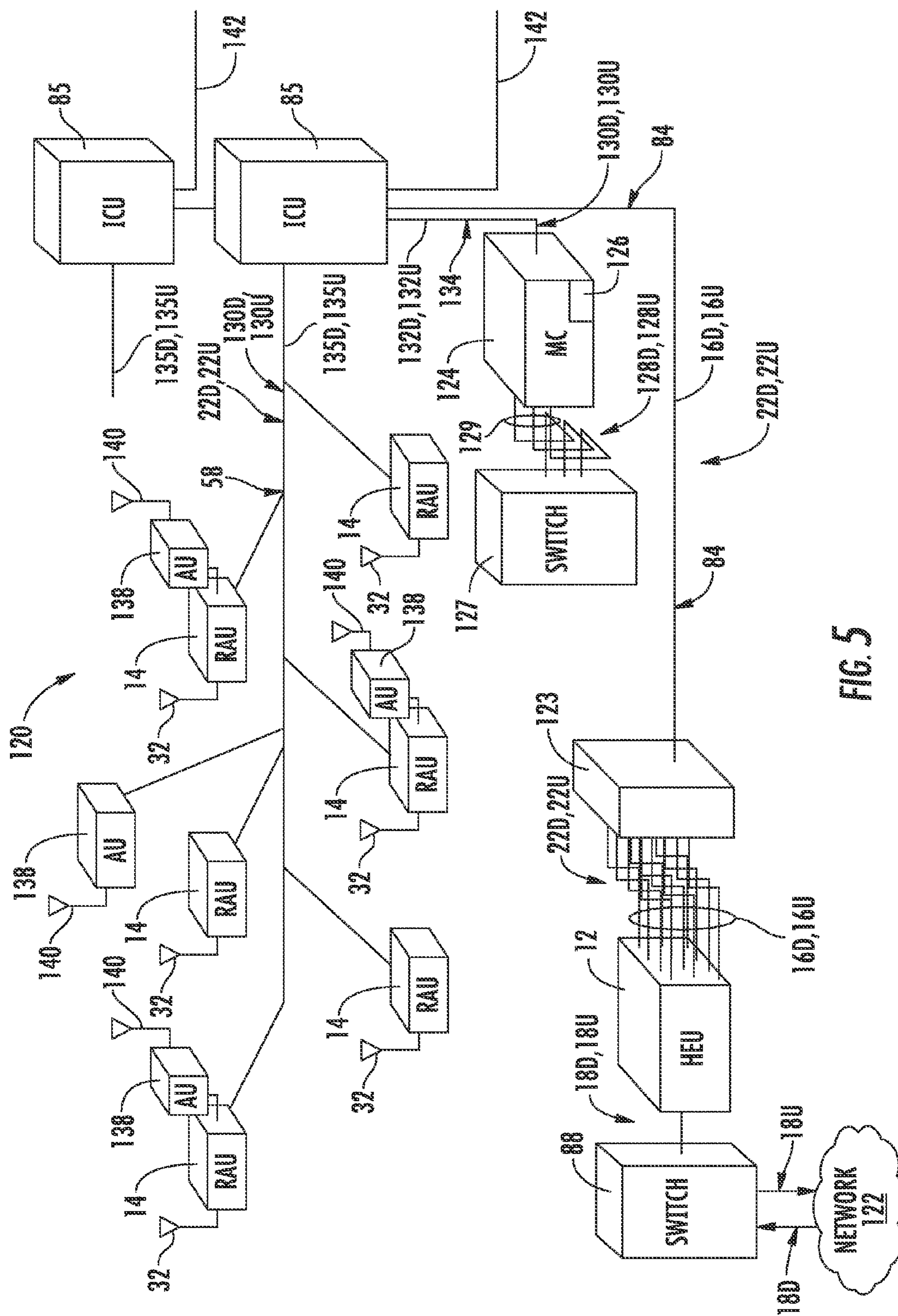


FIG. 4



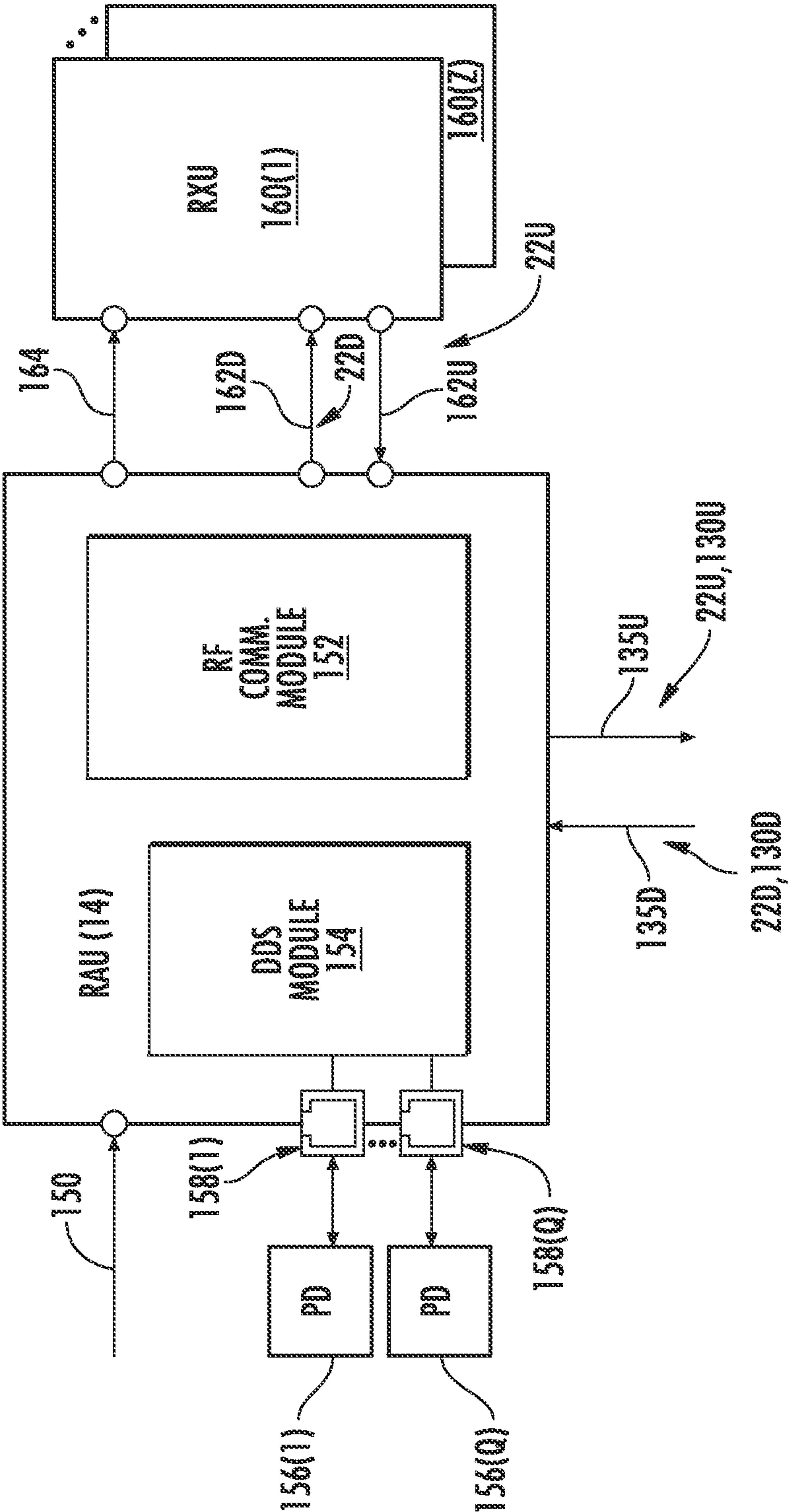
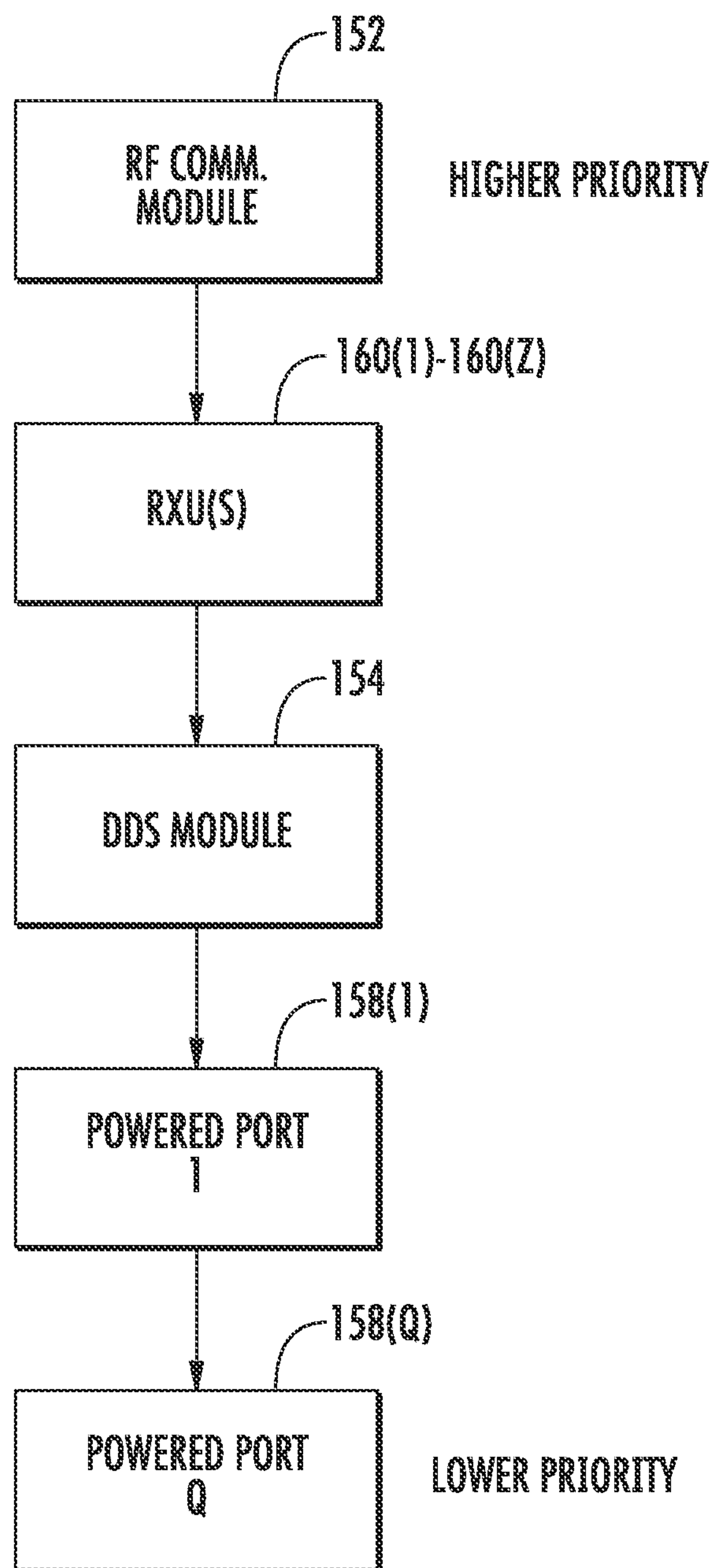


FIG. 6

**FIG. 7**

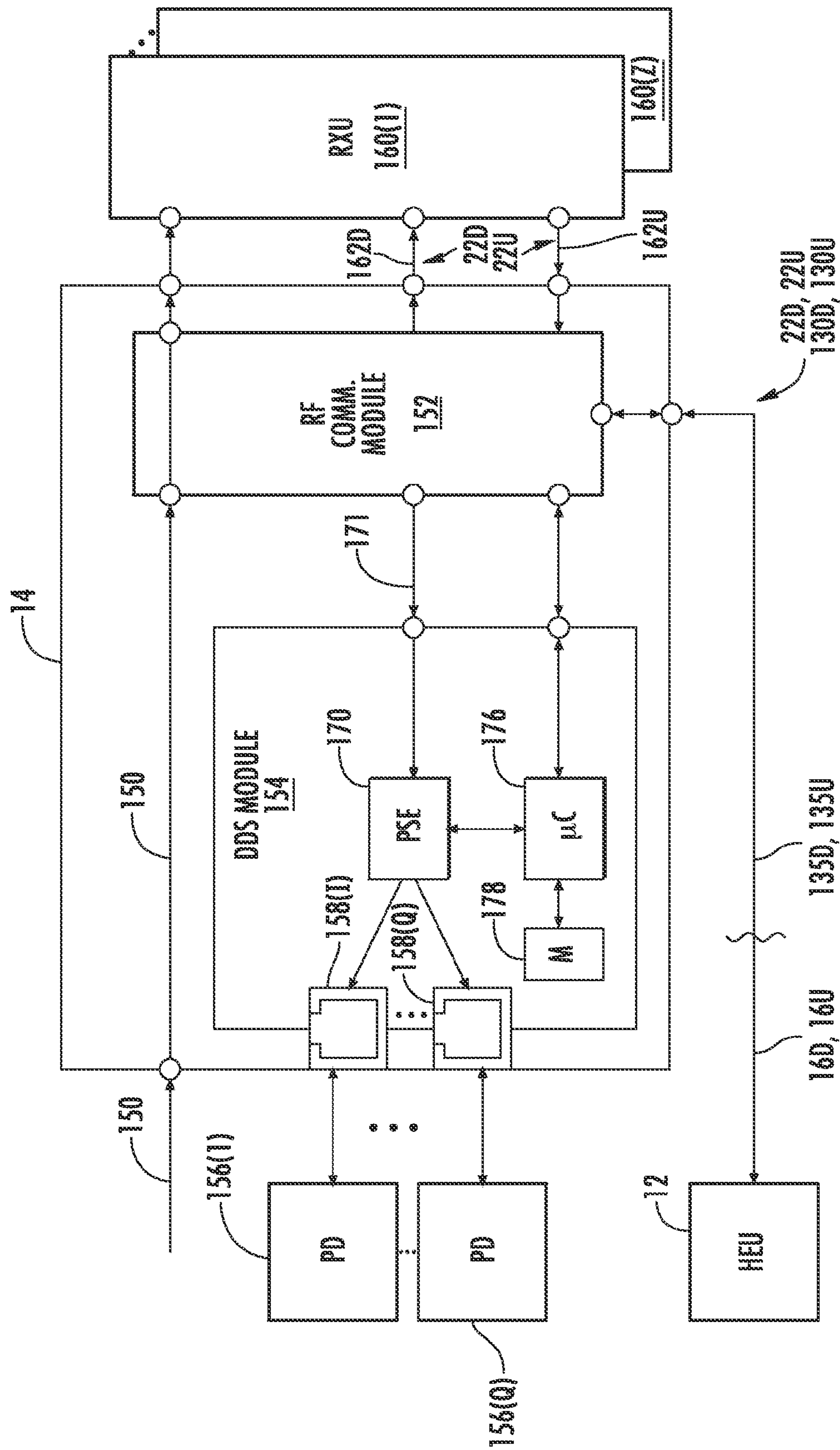


FIG. 8

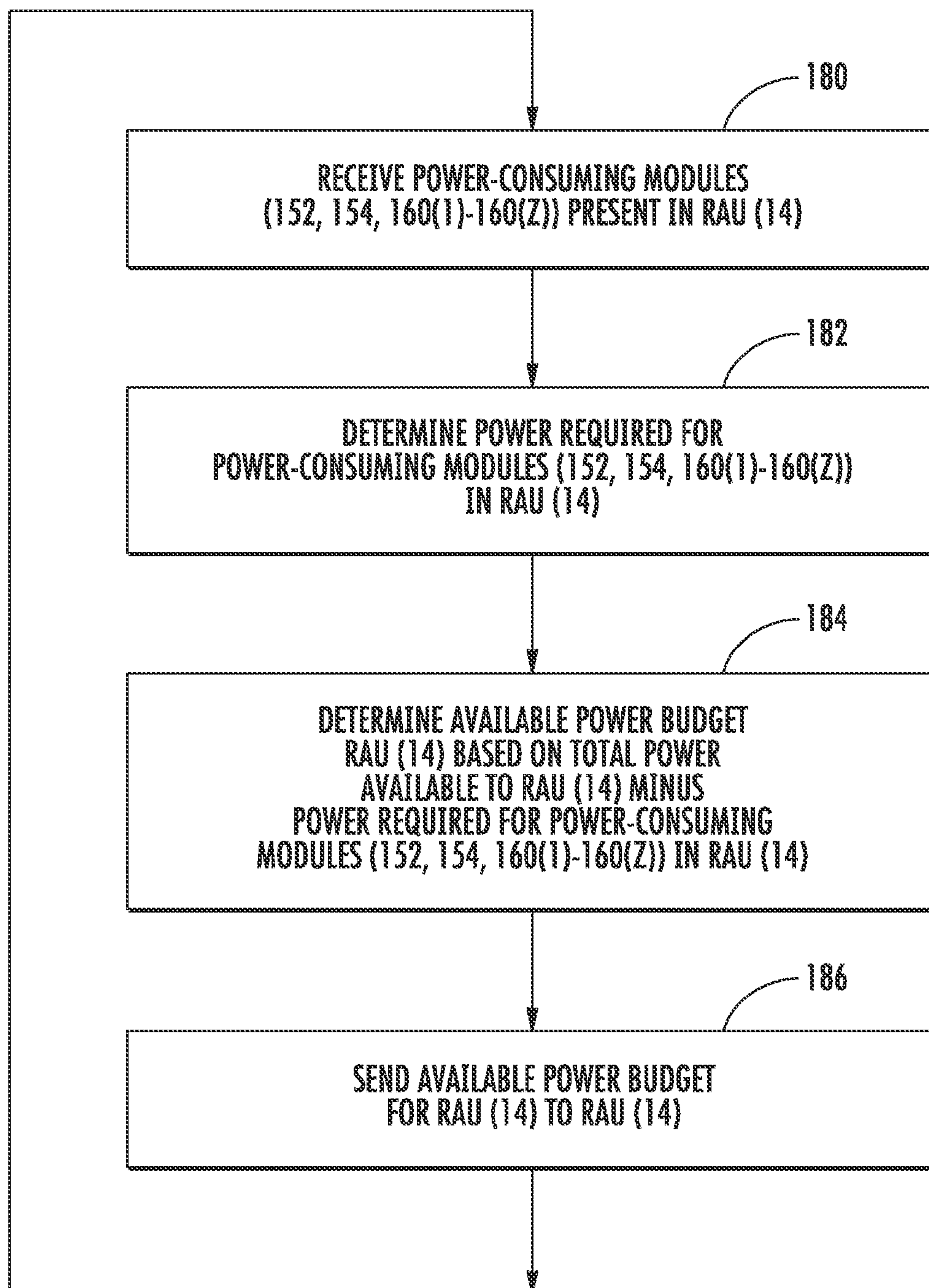


FIG. 9

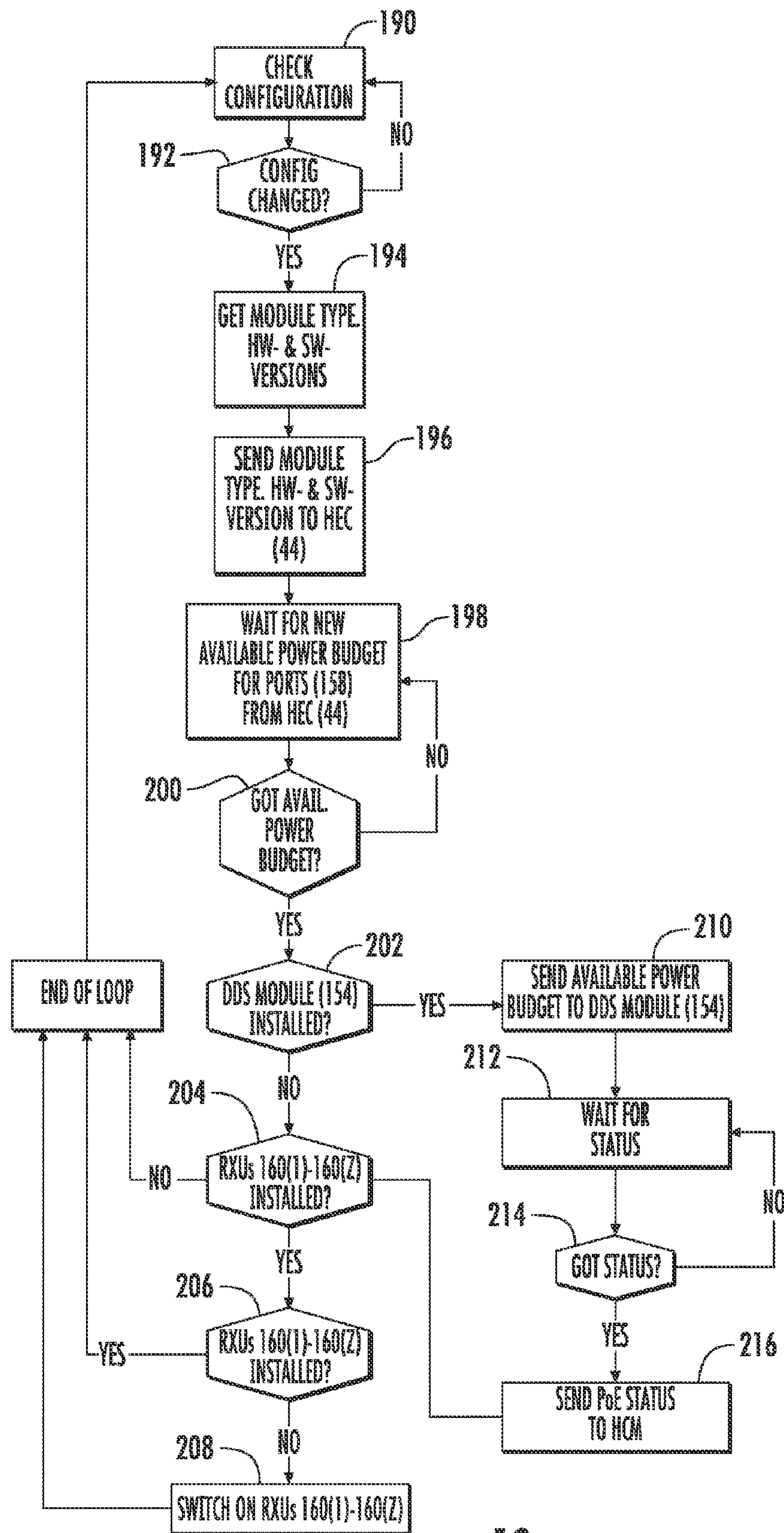


FIG. 10

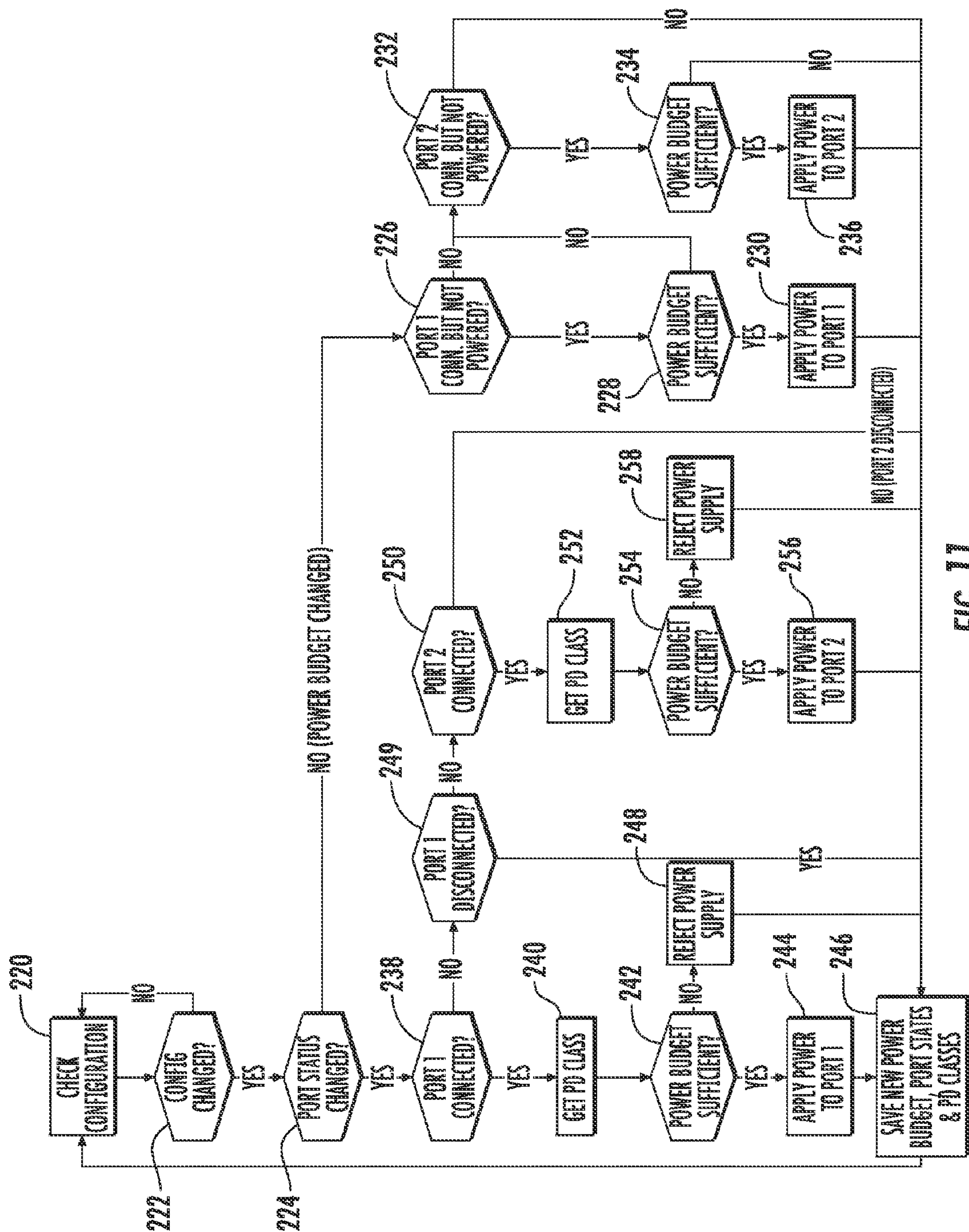
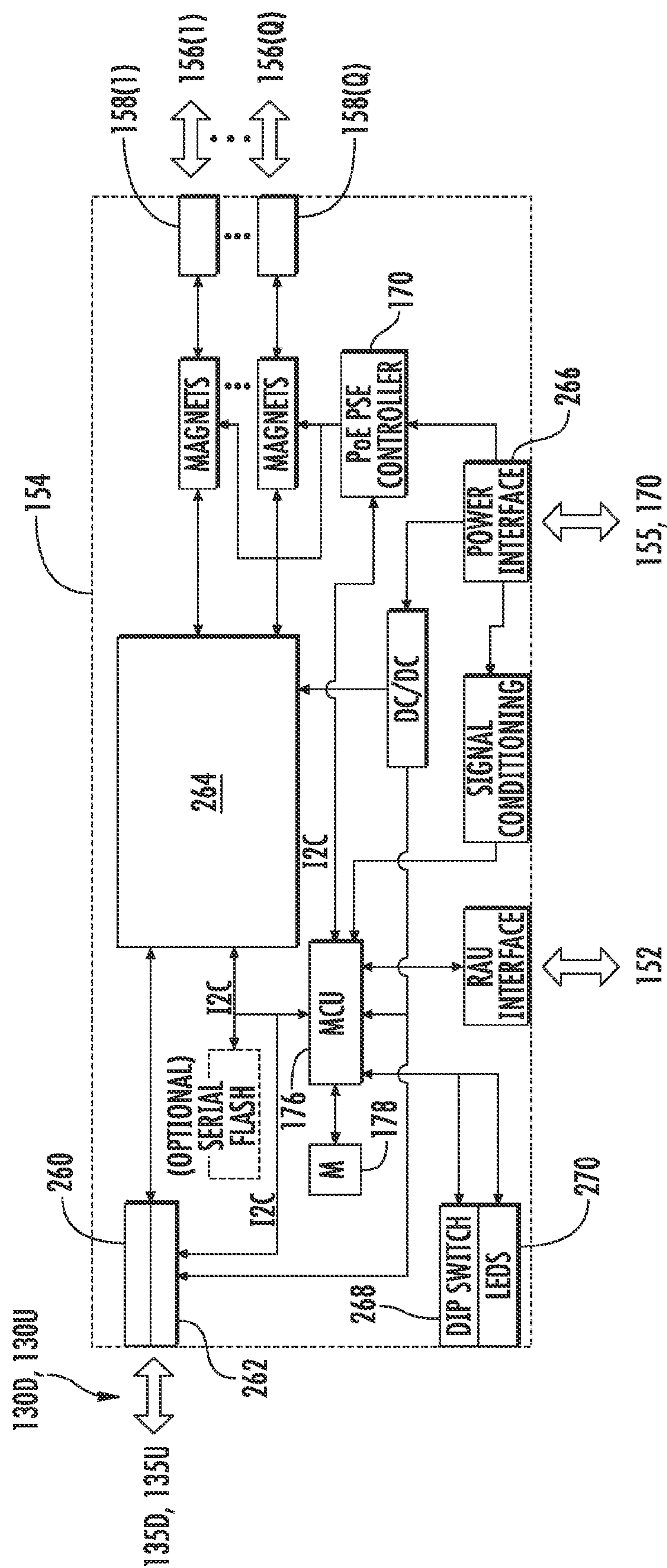


FIG. 11



23

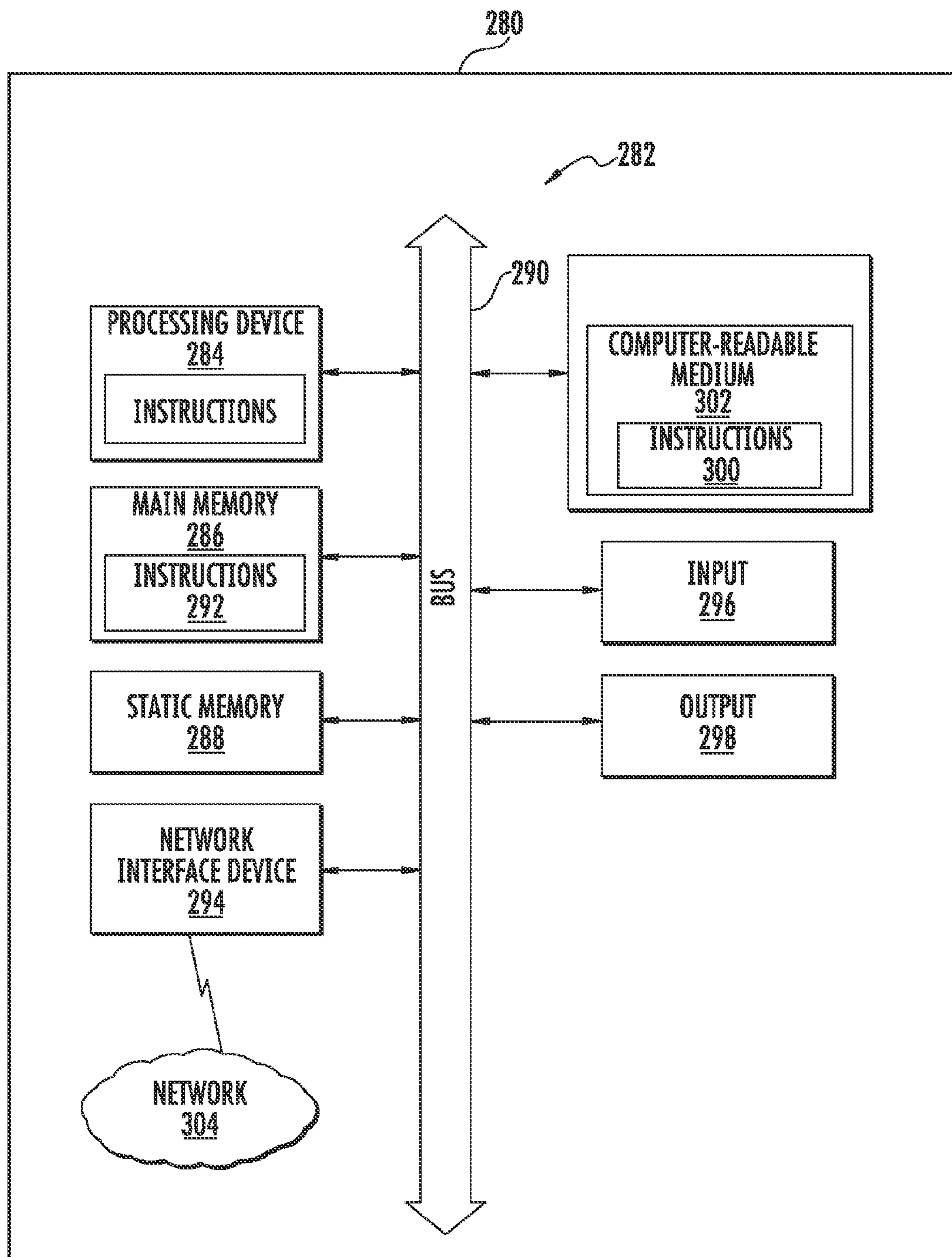


FIG. 13

POWER MANAGEMENT FOR REMOTE ANTENNA UNITS IN DISTRIBUTED ANTENNA SYSTEMS

PRIORITY CLAIM

This application is a continuation of U.S. application Ser. No. 13/860,017, filed Apr. 10, 2013, which is a continuation of International Application No. PCT/US11/55861 filed Oct. 12, 2011, which claims the benefit of priority to U.S. Provisional Application No. 61/392,687, filed on Oct. 13, 2010, all of which are incorporated herein by reference.

RELATED APPLICATIONS

The present application is related to U.S. application Ser. No. 13/859,985, filed Apr. 10, 2013 and entitled "Local Power Management for Remote Antenna Units in Distributed Antenna Systems," which claims priority to U.S. Provisional Application No. 61/392,660, filed on Oct. 13, 2010, both of which are incorporated herein by reference in their entireties.

The present application is also related to U.S. Provisional Application No. 61/330,386 filed on May 2, 2010 and entitled "Providing Digital Data Services in Optical Fiber-Based Distributed Radio Frequency (RF) Communications Systems, and Related Components and Methods," which is incorporated herein by reference in its entirety.

The present application is also related to U.S. patent application Ser. No. 12/892,424 filed on Sep. 28, 2010 and entitled "Providing Digital Data Services in Optical Fiber-Based Distributed Radio Frequency (RF) Communications Systems, and Related Components and Methods," which is incorporated herein by reference in its entirety.

The present application is also related to U.S. Provisional Application No. 61/230,463 filed on Jul. 31, 2009 and entitled "Optical Fiber-Based Distributed Antenna Systems, Components, and Related Methods for Calibration Thereof," which is incorporated herein by reference in its entirety.

The present application is also related to U.S. Provisional Application No. 61/230,472 filed on Jul. 31, 2009 and entitled "Optical Fiber-Based Distributed Antenna Systems, Components, and Related Methods for Monitoring the Status Thereof," which is incorporated herein by reference in its entirety.

BACKGROUND

1. Field of the Disclosure

The technology of the disclosure relates to power management in remote antenna units in distributed antenna systems for distributing radio frequency (RF) signals to the remote antenna units.

2. Technical Background

Wireless communication is rapidly growing, with ever-increasing demands for high-speed mobile data communication. As an example, so-called "wireless fidelity" or "WiFi" systems and wireless local area networks (WLANs) are being deployed in many different types of areas (e.g., coffee shops, airports, libraries, etc.). Distributed antenna systems communicate with wireless devices called "clients," which must reside within the wireless range or "cell coverage area" in order to communicate with an access point device.

One approach to deploying a distributed antenna system involves the use of radio frequency (RF) antenna coverage areas, also referred to as "antenna coverage areas." The antenna coverage areas are provided by remote antenna units in the distributed antenna system. Remote antenna units can

provide antenna coverage areas having radii in the range from a few meters up to twenty (20) meters as an example. If the antenna coverage areas provided each cover a small area, there are typically only a few users (clients) per antenna coverage area. This allows for minimizing the amount of RF bandwidth shared among the wireless system users. It may be desirable to provide antenna coverage areas in a building or other facility to provide indoor distributed antenna system access to clients within the building or facility. It may also be desirable to employ optical fiber to distribute RF communications signals to provide an optical fiber-based distributed antenna system. Distribution of RF communications signals over optical fiber can include Radio-over-Fiber (RoF) distribution. Benefits of optical fiber include increased bandwidth.

Remote antenna units may contain power-consuming circuits and other components that are involved in processing RF communications signals. For example, remote antenna units provided in an optical-fiber based distributed antenna system may include electrical-to-optical (E/O) converters and optical-to-electrical (O/E) converters that require power to operate. The E/O and O/E converters convert downlink optical RF communications signals to downlink electrical RF communications signals and uplink electrical RF communications signals to uplink optical RF communications signals, respectively. Other power-consuming components may be included in the remote antenna unit. A local power source can be provided at the remote antenna units to supply power to power-consuming components in the remote antenna units. Alternatively, to avoid providing a local power source, a remote power source can be provided that provides power over power lines routed to the remote antenna units. The power lines may be provided in separate cabling or bundled in a hybrid cable with communications lines routed to the remote antenna units.

It is important that a sufficient amount of power be provided to the remote antenna unit to properly power the power-consuming components provided therein. Otherwise, the power-consuming components in the remote antenna unit may not properly operate and may not provide intended services for the distributed antenna system. In the case of multiple power-consuming components provided in a remote antenna unit, power provided to the remote antenna unit is split among the multiple components. In this case, it is also important that the power be managed to sufficiently power each of the power-consuming components.

SUMMARY OF THE DETAILED DESCRIPTION

Embodiments disclosed in the detailed description include power management for a remote antenna unit(s) (RAUs) in a distributed antenna system, and related devices, systems, methods, and computer-readable media. The distributed antenna system may distribute radio frequency (RF) communications signals to RAUs for communicating to client devices. As a non-limiting example, the distributed antenna system may be an optical fiber-based distributed antenna system. Power can be managed for an RAU configured to power modules and devices that may require more power to operate than power available to the RAU. For example, the RAU may be configured to include power-consuming RAU modules to provide distributed antenna system-related services. As another example, the RAU may be configured to provide power to external power-consuming devices through powered ports in the RAU. Depending on the configuration of the RAU, the power-consuming RAU modules and/or external power-consuming devices may demand more power than is available at the RAU. In this instance, the power available

at the RAU can be distributed to the power-consuming modules and devices based on the priority of services desired to be provided by the RAU.

In one embodiment, a power management device for remotely managing power consumed at an RAU in a distributed antenna system is provided. The power management device comprises a remote controller communicatively coupled to at least one RAU configured to provide power to at least one external power-consuming device connected to the at least one powered port. The remote controller is configured to communicate with the at least one RAU to determine an available power budget for the at least one powered port. The remote controller is also configured to communicate the available power budget for the at least one powered port in the at least one RAU to the at least one RAU.

In another embodiment, a method of remotely managing power consumed at an RAU in a distributed antenna system is provided. The method includes communicating with at least one RAU configured to provide power to at least one external power-consuming device connected to the at least one powered port to determine an available power budget for the at least one powered port. The method also includes communicating the available power budget for the at least one powered port in the at least one RAU to the at least one RAU.

In another embodiment, a computer-readable medium is provided. The computer-readable medium stores one or more programs, the one or more programs comprising instructions, which when executed by a remote controller in a distributed antenna system and remotely located from an RAU, cause the remote controller to communicate with at least one RAU provided in a distributed antenna system to determine an available power budget for at least one powered port and provided in the at least one RAU configured to provide power to at least one external power-consuming device connected to the at least one powered port. The instructions further cause the remote controller to communicate the available power budget for the at least one powered port in the at least one RAU to the at least one RAU.

In another embodiment, an RAU for a distributed antenna system is provided. The RAU comprises at least one power-consuming RAU module. As non-limiting examples, the at least one power-consuming RAU module may be comprised of at least one of an RF communications module configured to provide RF communications services, and a digital data services (DDS) module configured to provide DDS. The RAU further comprises at least one powered port configured to provide power to at least one external power-consuming device connected to the at least one powered port. The RAU further comprises a controller configured to receive an available power budget for the at least one powered port from a remote controller in a distributed antenna system. The RAU controller is further configured to enable power for the at least one powered port if the available power budget is sufficient to power the at least one external power-consuming device connected to the at least one powered port.

In another embodiment, a method of managing power consumed at an RAU in a distributed antenna system is provided. The method comprises receiving an available power budget for at least one powered port configured to provide power to at least one external power-consuming device connected to the at least one powered port based on power required by at least one power-consuming RAU module. As non-limiting examples, the at least one power-consuming RAU module may be comprised of at least one of an RF communications module configured to provide RF communications services, and a digital data services (DDS) module configured to provide DDS. The method further comprises enabling power for

the at least one powered port if an available power budget is sufficient to power the at least one external power-consuming device connected to the at least one powered port.

In another embodiment, a computer-readable medium is provided. The computer-readable medium stores one or more programs, the one or more programs comprising instructions, which when executed by an RAU controller in at least one RAU provided in a distributed antenna system, cause the RAU controller to receive an available power budget from a remote controller for at least one powered port in an RAU provided in a distributed antenna system, the RAU configured to provide power to at least one external power-consuming device connected to the at least one powered port based on power required by at least one power-consuming RAU module. The instructions further cause the RAU controller to enable power for the at least one powered port if an available power budget is sufficient to power the at least one external power-consuming device connected to the at least one powered port.

It is to be understood that both the foregoing general description and the following detailed description present embodiments, and are intended to provide an overview or framework for understanding the nature and character of the disclosure.

The accompanying drawings are included to provide a further understanding, and are incorporated into and constitute a part of this specification. The drawings illustrate various embodiments, and together with the description serve to explain the principles and operation of the concepts disclosed.

BRIEF DESCRIPTION OF THE FIGURES

FIG. 1 is a schematic diagram of an exemplary distributed antenna system;

FIG. 2 is a more detailed schematic diagram of exemplary head-end equipment and a remote antenna unit (RAU) that can be deployed in the distributed antenna system of FIG. 1;

FIG. 3 is a partially schematic cut-away diagram of an exemplary building infrastructure in which the distributed antenna system in FIG. 1 can be employed;

FIG. 4 is a schematic diagram of another exemplary distributed antenna system;

FIG. 5 is a schematic diagram of an exemplary embodiment of providing digital data services to RAUs in a distributed antenna system;

FIG. 6 is a schematic diagram of an exemplary RAU configured with power-consuming components for providing radio frequency (RF) communications services, digital data services, external power to digital data service devices, and a remote expansion unit;

FIG. 7 is an exemplary priority scheme for providing power to power-consuming components that may be present in an RAU;

FIG. 8 is a schematic diagram of an exemplary RAU that includes remote power management for managing power provided to internal power-consuming modules and external power-consuming modules connected to the RAU;

FIG. 9 is a flowchart illustrating an exemplary remote power management process provided by the controller in FIG. 8 to remotely manage power at the RAU;

FIG. 10 is a flowchart illustrating an exemplary power management process provided by the RAU to manage power at the RAU at initialization and when configuration changes are made to the RAU;

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FIG. 11 is a flowchart illustrating an exemplary power management process provided by the RAU to manage power provided to powered ports provided in an RAU;

FIG. 12 is an exemplary digital data services (DDS) module that can be provided in the RAU to provide digital data services at the RAU; and

FIG. 13 is a schematic diagram of a generalized representation of an exemplary computer system that can be included in a head-end controller (HEC), which is adapted to execute instructions from an exemplary computer-readable medium to perform the power management functions in the RAU.

DETAILED DESCRIPTION

Reference will now be made in detail to the embodiments, examples of which are illustrated in the accompanying drawings, in which some, but not all embodiments are shown. Indeed, the concepts may be embodied in many different forms and should not be construed as limiting herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Whenever possible, like reference numbers will be used to refer to like components or parts.

Embodiments disclosed in the detailed description include power management for a remote antenna unit(s) (RAUs) in a distributed antenna system, and related devices, systems, methods, and computer-readable media. The distributed antenna system may distribute radio frequency (RF) communications signals to RAUs for communicating to client devices. As a non-limiting example, the distributed antenna system may be an optical fiber-based distributed antenna system. Power can be managed for an RAU configured to power modules and devices that may require more power to operate than power available to the RAU. For example, the RAU may be configured to include power-consuming RAU modules to provide distributed antenna system related services. As another example, the RAU may be configured to provide power to external power-consuming devices through powered ports in the RAU. Depending on the configuration of the RAU, the power-consuming RAU modules and/or external power-consuming devices may demand more power than is available at the RAU. In this instance, the power available at the RAU can be distributed to the power-consuming modules and devices based on the priority of services desired to be provided by the RAU.

Before discussing power management for RAUs provided in distributed antenna systems and related components and methods starting at FIG. 5, FIGS. 1-4 are provided and first discussed below. FIGS. 1-4 provide examples of distributed antenna systems, including those according to the embodiments described herein.

FIG. 1 is a schematic diagram of an exemplary distributed antenna system. In this embodiment, the distributed antenna system is an optical fiber-based distributed antenna system 10; however, other types of distributed antenna systems are also possible. The optical fiber-based distributed antenna system 10 is configured to create one or more antenna coverage areas for establishing communications with wireless client devices located in the RF range of the antenna coverage areas. The optical fiber-based distributed antenna system 10 provides RF communications services (e.g., cellular services). In this embodiment, the optical fiber-based distributed antenna system 10 includes head-end equipment in the form of a head-end unit (HEU) 12, one or more remote antenna units (RAUs) 14, and an optical fiber 16 that optically couples the HEU 12 to the RAU 14. The HEU 12 is configured to receive communications over downlink electrical RF communica-

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tions signals 18D from a source or sources, such as a network or carrier as examples, and provide such communications to the RAU 14. The HEU 12 is also configured to return communications received from the RAU 14, via uplink electrical RF communications signals 18U, back to the source or sources. In this regard in this embodiment, the optical fiber 16 includes at least one downlink optical fiber 16D to carry signals communicated from the HEU 12 to the RAU 14 and at least one uplink optical fiber 16U to carry signals communicated from the RAU 14 back to the HEU 12.

The optical fiber-based distributed antenna system 10 has an antenna coverage area 20 that can be substantially centered about the RAU 14. The antenna coverage area 20 of the RAU 14 forms an RF coverage area 21. The HEU 12 is adapted to perform or to facilitate any one of a number of Radio-over-Fiber (RoF) applications, such as radio frequency identification (RFID), wireless local-area network (WLAN) communication, or cellular phone service. Shown within the antenna coverage area 20 is a client device 24 in the form of a mobile device as an example, which may be a cellular telephone as an example. The client device 24 can be any device that is capable of receiving RF communications signals. The client device 24 includes an antenna 26 (e.g., a wireless card) adapted to receive and/or send electromagnetic RF communications signals.

With continuing reference to FIG. 1, to communicate the electrical RF communications signals over the downlink optical fiber 16D to the RAU 14, to in turn be communicated to the client device 24 in the antenna coverage area 20 formed by the RAU 14, the HEU 12 includes an electrical-to-optical (E/O) converter 28. The E/O converter 28 converts the downlink electrical RF communications signals 18D to downlink optical RF communications signals 22D to be communicated over the downlink optical fiber 16D. The RAU 14 includes an optical-to-electrical (O/E) converter 30 to convert received downlink optical RF communications signals 22D back to electrical RF communications signals to be communicated wirelessly through an antenna 32 of the RAU 14 to client devices 24 located in the antenna coverage area 20.

Similarly, the antenna 32 is also configured to receive wireless RF communications from client devices 24 in the antenna coverage area 20. In this regard, the antenna 32 receives wireless RF communications from client devices 24 and communicates electrical RF communications signals representing the wireless RF communications to an E/O converter 34 in the RAU 14. The E/O converter 34 converts the electrical RF communications signals into uplink optical RF communications signals 22U to be communicated over the uplink optical fiber 16U. An O/E converter 36 provided in the HEU 12 converts the uplink optical RF communications signals 22U into uplink electrical RF communications signals, which can then be communicated as uplink electrical RF communications signals 18U back to a network or other source. The HEU 12 in this embodiment is not able to distinguish the location of the client device 24 in this embodiment. The client device 24 could be in the range of any antenna coverage area 20 formed by an RAU 14.

FIG. 2 is a more detailed schematic diagram of the exemplary optical fiber-based distributed antenna system 10 of FIG. 1 that provides electrical RF service signals for a particular RF service or application. In an exemplary embodiment, the HEU 12 includes a service unit 37 that provides electrical RF service signals by passing (or conditioning and then passing) such signals from one or more outside networks 38 via a network link 39. In a particular example embodiment, this includes providing WLAN signal distribution as specified in the Institute of Electrical and Electronics Engineers

(IEEE) 802.11 standard, i.e., in the frequency range from 2.4 to 2.5 GigaHertz (GHz) and from 5.0 to 6.0 GHz. Any other electrical RF communications signal frequencies are possible. In another exemplary embodiment, the service unit **37** provides electrical RF service signals by generating the signals directly. In another exemplary embodiment, the service unit **37** coordinates the delivery of the electrical RF service signals between client devices **24** within the antenna coverage area **20**.

With continuing reference to FIG. 2, the service unit **37** is electrically coupled to the E/O converter **28** that receives the downlink electrical RF communications signals **18D** from the service unit **37** and converts them to corresponding downlink optical RF communications signals **22D**. In an exemplary embodiment, the E/O converter **28** includes a laser suitable for delivering sufficient dynamic range for the RoF applications described herein, and optionally includes a laser driver/amplifier electrically coupled to the laser. Examples of suitable lasers for the E/O converter **28** include, but are not limited to, laser diodes, distributed feedback (DFB) lasers, Fabry-Perot (FP) lasers, and vertical cavity surface emitting lasers (VCSELs).

With continuing reference to FIG. 2, the HEU **12** also includes the O/E converter **36**, which is electrically coupled to the service unit **37**. The O/E converter **36** receives the uplink optical RF communications signals **22U** and converts them to corresponding uplink electrical RF communications signals **18U**. In an example embodiment, the O/E converter **36** is a photodetector, or a photodetector electrically coupled to a linear amplifier. The E/O converter **28** and the O/E converter **36** constitute a “converter pair” **35**, as illustrated in FIG. 2.

In accordance with an exemplary embodiment, the service unit **37** in the HEU **12** can include an RF communications signal conditioner unit **40** for conditioning the downlink electrical RF communications signals **18D** and the uplink electrical RF communications signals **18U**, respectively. The service unit **37** can include a digital signal processing unit (“digital signal processor”) **42** for providing to the RF communications signal conditioner unit **40** an electrical signal that is modulated onto an RF carrier to generate a desired downlink electrical RF communications signal **18D**. The digital signal processor **42** is also configured to process a demodulation signal provided by the demodulation of the uplink electrical RF communications signal **18U** by the RF communications signal conditioner unit **40**. The service unit **37** in the HEU **12** can also include an optional head-end unit controller (HEC) **44** (or “controller **44**”) for processing data and otherwise performing logic and computing operations, and a memory unit **46** for storing data, such as data to be transmitted over a WLAN or other network for example.

With continuing reference to FIG. 2, the RAU **14** also includes a converter pair **48** comprising the O/E converter **30** and the E/O converter **34**. The O/E converter **30** converts the received downlink optical RF communications signals **22D** from the HEU **12** back into downlink electrical RF communications signals **50D**. The E/O converter **34** converts uplink electrical RF communications signals **50U** received from the client device **24** into the uplink optical RF communications signals **22U** to be communicated to the HEU **12**. The O/E converter **30** and the E/O converter **34** are electrically coupled to the antenna **32** via an RF signal-directing element **52**, such as a circulator for example. The RF signal-directing element **52** serves to direct the downlink electrical RF communications signals **50D** and the uplink electrical RF communications signals **50U**, as discussed below. In accordance with an exemplary embodiment, the antenna **32** can include any type of antenna, including but not limited to one or more patch

antennas, such as disclosed in U.S. patent application Ser. No. 11/504,999, now U.S. Pat. No. 7,627,250, filed Aug. 16, 2006, entitled “Radio-over-Fiber Transponder With A Dual-Band Patch Antenna System,” and U.S. patent application Ser. No. 11/451,553, filed Jun. 12, 2006, entitled “Centralized Optical Fiber-based Wireless Picocellular Systems and Methods,” both of which are incorporated herein by reference in their entireties.

With continuing reference to FIG. 2, the optical fiber-based distributed antenna system **10** also includes a power supply **54** that provides an electrical power signal **56**. The power supply **54** is electrically coupled to the HEU **12** for powering the power-consuming elements therein. In an exemplary embodiment, an electrical power line **58** runs through the HEU **12** and over to the RAU **14** to power the O/E converter **30** and the E/O converter **34** in the converter pair **48**, the optional RF signal-directing element **52** (unless the RF signal-directing element **52** is a passive device such as a circulator for example), and any other power-consuming elements provided. In an exemplary embodiment, the electrical power line **58** includes two wires **60** and **62** that carry a single voltage and that are electrically coupled to a DC power converter **64** at the RAU **14**. The DC power converter **64** is electrically coupled to the O/E converter **30** and the E/O converter **34** in the converter pair **48**, and changes the voltage or levels of the electrical power signal **56** to the power level(s) required by the power-consuming components in the RAU **14**. In an exemplary embodiment, the DC power converter **64** is either a DC/DC power converter or an AC/DC power converter, depending on the type of electrical power signal **56** carried by the electrical power line **58**. In another example embodiment, the electrical power line **58** (dashed line) runs directly from the power supply **54** to the RAU **14** rather than from or through the HEU **12**. In another example embodiment, the electrical power line **58** includes more than two wires and may carry multiple voltages.

To provide further exemplary illustration of how an optical fiber-based distributed antenna system can be deployed indoors, FIG. 3 is provided. FIG. 3 is a partially schematic cut-away diagram of a building infrastructure **70** employing an optical fiber-based distributed antenna system. The system may be the optical fiber-based distributed antenna system **10** of FIGS. 1 and 2. The building infrastructure **70** generally represents any type of building in which the optical fiber-based distributed antenna system **10** can be deployed. As previously discussed with regard to FIGS. 1 and 2, the optical fiber-based distributed antenna system **10** incorporates the HEU **12** to provide various types of communications services to coverage areas within the building infrastructure **70**, as an example. For example, as discussed in more detail below, the optical fiber-based distributed antenna system **10** in this embodiment is configured to receive wireless RF communications signals and convert the RF communications signals into RoF signals to be communicated over the optical fiber **16** to multiple RAUs **14**. The optical fiber-based distributed antenna system **10** in this embodiment can be, for example, an indoor distributed antenna system (IDAS) to provide wireless service inside the building infrastructure **70**. These wireless signals can include cellular service, wireless services such as RFID tracking, Wireless Fidelity (WiFi), local area network (LAN), WLAN, and combinations thereof, as examples.

With continuing reference to FIG. 3, the building infrastructure **70** in this embodiment includes a first (ground) floor **72**, a second floor **74**, and a third floor **76**. The floors **72**, **74**, **76** are serviced by the HEU **12** through a main distribution frame **78** to provide antenna coverage areas **80** in the building infrastructure **70**. Only the ceilings of the floors **72**, **74**, **76** are

shown in FIG. 3 for simplicity of illustration. In the example embodiment, a main cable **82** has a number of different sections that facilitate the placement of a large number of RAUs **14** in the building infrastructure **70**. Each RAU **14** in turn services its own coverage area in the antenna coverage areas **80**. The main cable **82** can include, for example, a riser cable **84** that carries all of the downlink and uplink optical fibers **16D**, **16U** to and from the HEU **12**. The riser cable **84** may be routed through an interconnect unit (ICU) **85**. The ICU **85** may be provided as part of or separate from the power supply **54** in FIG. 2. The ICU **85** may also be configured to provide power to the RAUs **14** via the electrical power line **58**, as illustrated in FIG. 2 and discussed above, provided inside an array cable **87**, or tail cable or home-run tether cable as other examples, and distributed with the downlink and uplink optical fibers **16D**, **16U** to the RAUs **14**. The main cable **82** can include one or more multi-cable (MC) connectors adapted to connect select downlink and uplink optical fibers **16D**, **16U**, along with an electrical power line, to a number of optical fiber cables **86**.

The main cable **82** enables the multiple optical fiber cables **86** to be distributed throughout the building infrastructure **70** (e.g., fixed to the ceilings or other support surfaces of each floor **72**, **74**, **76**) to provide the antenna coverage areas **80** for the first, second, and third floors **72**, **74**, and **76**. In an example embodiment, the HEU **12** is located within the building infrastructure **70** (e.g., in a closet or control room), while in another example embodiment, the HEU **12** may be located outside of the building infrastructure **70** at a remote location. A base transceiver station (BTS) **88**, which may be provided by a second party such as a cellular service provider, is connected to the HEU **12**, and can be co-located or located remotely from the HEU **12**. A BTS is any station or source that provides an input signal to the HEU **12** and can receive a return signal from the HEU **12**. In a typical cellular system, for example, a plurality of BTSs are deployed at a plurality of remote locations to provide wireless telephone coverage. Each BTS serves a corresponding cell, and when a mobile client device enters the cell, the BTS communicates with the mobile client device. Each BTS can include at least one radio transceiver for enabling communication with one or more subscriber units operating within the associated cell. As another example, wireless repeaters or bi-directional amplifiers could also be used to serve a corresponding cell in lieu of a BTS. Alternatively, radio input could be provided by a repeater or picocell as other examples.

The optical fiber-based distributed antenna system **10** in FIGS. 1-3 and described above provides point-to-point communications between the HEU **12** and the RAU **14**. Each RAU **14** communicates with the HEU **12** over a distinct downlink and uplink optical fiber pair to provide the point-to-point communications. Whenever an RAU **14** is installed in the optical fiber-based distributed antenna system **10**, the RAU **14** is connected to a distinct downlink and uplink optical fiber pair connected to the HEU **12**. The downlink and uplink optical fibers **16U**, **16D** may be provided in a fiber optic cable. Multiple downlink and uplink optical fiber pairs can be provided in a fiber optic cable to service multiple RAUs **14** from a common fiber optic cable. For example, with reference to FIG. 3, RAUs **14** installed on a given floor **72**, **74**, or **76** may be serviced from the same optical fiber **16**. In this regard, the optical fiber **16** may have multiple nodes where distinct downlink and uplink optical fiber pairs can be connected to a given RAU **14**. One downlink optical fiber **16** could be provided to support multiple channels each using wavelength-division multiplexing (WDM), as discussed in U.S. patent application Ser. No. 12/892,424 entitled "Providing Digital

Data Services in Optical Fiber-Based Distributed Radio Frequency (RF) Communications Systems, and Related Components and Methods," incorporated herein by reference in its entirety. Other options for WDM and frequency-division multiplexing (FDM) are also disclosed in U.S. patent application Ser. No. 12/892,424, any of which can be employed in any of the embodiments disclosed herein.

FIG. 4 is a schematic diagram of another exemplary distributed antenna system **90**. In this embodiment, the distributed antenna system **90** is an optical fiber-based distributed antenna system comprised of three main components. One or more radio interfaces provided in the form of radio interface modules (RIMs) **92(1)-92(M)** in this embodiment are provided in an HEU **94** to receive and process downlink electrical RF communications signals **96(1)-96(R)** prior to optical conversion into downlink optical RF communications signals. The processing of the downlink electrical RF communications signals **96(1)-96(R)** can include any of the processing previously described above in the HEU **12** in FIG. 2. The notations "1-R" and "1-M" indicate that any number of the referenced component, 1-R and 1-M, respectively, may be provided. As will be described in more detail below, the HEU **94** is configured to accept a plurality of RIMs **92(1)-92(M)** as modular components that can easily be installed and removed or replaced in the HEU **94**. In one embodiment, the HEU **94** is configured to support up to four (4) RIMs **92(1)-92(M)** as an example.

Each RIM **92(1)-92(M)** can be designed to support a particular type of radio source or range of radio sources (i.e., frequencies) to provide flexibility in configuring the HEU **94** and the optical fiber-based distributed antenna system **90** to support the desired radio sources. For example, one RIM **92** may be configured to support the Personal Communication Services (PCS) radio band. Another RIM **92** may be configured to support the 700 MHz radio band. In this example, by inclusion of these RIMs **92**, the HEU **94** would be configured to support and distribute RF communications signals on both PCS and LTE **700** radio bands. RIMs **92** may be provided in the HEU **94** that support any frequency bands desired, including but not limited to US Cellular band, PCS (Personal Communication Services) band, AWS (Advanced Wireless Services) band, 700 MHz band, Global System for Mobile communications (GSM) **900**, GSM **1800**, UMTS. RIMs **92** may be provided in the HEU **94** that support any wireless technologies desired, including but not limited to CDMA (Code Division Multiple Access), CDMA200, 1 xRTT, EV-DO (Evolution—Data Only), UMTS (Universal Mobile Telecommunication System), HSPA (High-speed Packet Access), GSM, GPRS (General Packet Radio Services), EDGE (Enhanced Data GSM Environment), TDMA (Time Division Multiple Access), LTE (Long Term Evolution), iDEN, and CDPD (Cellular Digital Packet Data).

RIMs **92** may be provided in the HEU **94** that support any frequencies desired, including but not limited to US FCC and Industry Canada frequencies (824-849 MHz on uplink and 869-894 MHz on downlink), US FCC and Industry Canada frequencies (1850-1915 MHz on uplink and 1930-1995 MHz on downlink), US FCC and Industry Canada frequencies (1710-1755 MHz on uplink and 2110-2155 MHz on downlink), US FCC frequencies (698-716 MHz and 776-787 MHz on uplink and 728-746 MHz on downlink). EU R & TTE frequencies (880-915 MHz on uplink and 925-960 MHz on downlink), EU R & TTE frequencies (1710-1785 MHz on uplink and 1805-1880 MHz on downlink), EU R & TTE frequencies (1920-1980 MHz on uplink and 2110-2170 MHz on downlink), US FCC frequencies (806-824 MHz on uplink and 851-869 MHz on downlink), US FCC frequencies (896-

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901 MHz on uplink and 929-941 MHz on downlink), US FCC frequencies (793-805 MHz on uplink and 763-775 MHz on downlink), and US FCC frequencies (2495-2690 MHz on uplink and downlink).

The downlink electrical RF communications signals **96(1)-96(R)** are provided to a plurality of optical interfaces provided in the form of optical interface modules (OIMs) **98(1)-98(N)** in this embodiment to convert the downlink electrical RF communications signals **96(1)-96(N)** into downlink optical signals **100(1)-100(R)**. The notation “1-N” indicates that any number of the referenced component 1-N may be provided. The OIMs **98** may be configured to provide one or more optical interface components (OICs) that contain O/E and E/O converters, as will be described in more detail below. The OIMs **98** support the radio bands that can be provided by the RIMs **92**, including the examples previously described above. Thus, in this embodiment, the OIMs **98** may support a radio band range from 400 MHz to 2700 MHz, as an example, so providing different types or models of OIMs **98** for narrower radio bands to support possibilities for different radio band-supported RIMs **92** provided in the HEU **94** is not required. Further, as an example, the OIMs **98s** may be optimized for sub-bands within the 400 MHz to 2700 MHz frequency range, such as 400-700 MHz, 700 MHz-1 GHz, 1 GHz-1.6 GHz, and 1.6 GHz-2.7 GHz, as examples.

The OIMs **98(1)-98(N)** each include E/O converters to convert the downlink electrical RF communications signals **96(1)-96(R)** to downlink optical signals **100(1)-100(R)**. The downlink optical signals **100(1)-100(R)** are communicated over downlink optical fiber(s) **103D** to a plurality of RAUs **102(1)-102(P)**. The notation “1-P” indicates that any number of the referenced component 1-P may be provided. O/E converters provided in the RAUs **102(1)-102(P)** convert the downlink optical signals **100(1)-100(R)** back into downlink electrical RF communications signals **96(1)-96(R)**, which are provided over links **104(1)-104(P)** coupled to antennas **106(1)-106(P)** in the RAUs **102(1)-102(P)** to client devices in the reception range of the antennas **106(1)-106(P)**.

E/O converters are also provided in the RAUs **102(1)-102(P)** to convert uplink electrical RF communications signals received from client devices through the antennas **106(1)-106(P)** into uplink optical signals **108(1)-108(R)** to be communicated over uplink optical fibers **103U** to the OIMs **98(1)-98(N)**. The OIMs **98(1)-98(N)** include O/E converters that convert the uplink optical signals **108(1)-108(R)** into uplink electrical RF communications signals **110(1)-110(R)** that are processed by the RIMs **92(1)-102(M)** and provided as uplink electrical RF communications signals **112(1)-112(R)**.

It may be desirable to provide both digital data services and RF communications services for client devices. For example, it may be desirable to provide digital data services and RF communications services in the building infrastructure **70** (FIG. 3) to client devices located therein. Wired and wireless devices may be located in the building infrastructure **70** that are configured to access digital data services. Examples of digital data services include, but are not limited to, Ethernet, WLAN, WiMax, WiFi, Digital Subscriber Line (DSL), and LTE, etc. Ethernet standards could be supported, including but not limited to 100 Megabits per second (Mbps) (i.e., fast Ethernet) or Gigabit (Gb) Ethernet, or ten Gigabit (10G) Ethernet. Examples of digital data devices include, but are not limited to, wired and wireless servers, wireless access points (WAPs), gateways, desktop computers, hubs, switches, remote radio heads (RRHs), baseband units (BBUs), and femtocells. A separate digital data services network can be provided to provide digital data services to digital data devices.

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FIG. 5 is a schematic diagram of an exemplary embodiment of providing digital data services over separate downlink and uplink optical fibers from RF communications services to RAUs in an optical fiber-based distributed antenna system **120**. The optical fiber-based distributed antenna system **120** is described as including some components provided in the optical fiber-based distributed antenna system **10** of FIGS. 1-3. These common components are illustrated in FIG. 5 with common element numbers with FIGS. 1-3. However, note that the optical fiber-based distributed antenna system **120** could also employ other components, including those in the optical fiber-based distributed antenna system **90** in FIG. 4.

As illustrated in FIG. 5, the HEU **12** is provided. The HEU **12** receives the downlink electrical RF communications signals **18D** from the BTS **88**. As previously discussed, the HEU **12** converts the downlink electrical RF communications signals **18D** to downlink optical RF communications signals **22D** to be distributed to the RAUs **14**. The HEU **12** is also configured to convert the uplink optical RF communications signals **22U** received from the RAUs **14** into uplink electrical RF communications signals **18U** to be provided to the BTS **88** and onto a network **122** connected to the BTS **88**. A patch panel **123** may be provided to receive the downlink and uplink optical fibers **16D**, **16U** configured to carry the downlink and uplink optical RF communications signals **22D**, **22U**. The downlink and uplink optical fibers **16D**, **16U** may be bundled together in one or more riser cables **84** and provided to one or more ICUs **85**, as previously discussed and illustrated in FIG. 3.

To provide digital data services in the optical fiber-based distributed antenna system **120** in this embodiment, a digital data services controller (also referred to as “DDS controller”) **124** in the form of a media converter in this example is provided. The DDS controller **124** can include only a media converter for provision media conversion functionality or can include additional functionality to facilitate digital data services. The DDS controller **124** is configured to provide digital data services over a communications link, interface, or other communications channel or line, which may be either wired, wireless, or a combination of both. The DDS controller **124** may include a housing configured to house digital media converters (DMCs) **126** to interface to a DDS switch **127** to support and provide digital data services. For example, the DDS switch **127** could be an Ethernet switch. The DDS switch **127** may be configured to provide Gigabit (Gb) Ethernet digital data service as an example. The DMCs **126** are configured to convert electrical digital signals to optical digital signals, and vice versa. The DMCs **126** may be configured for plug and play installation (i.e., installation and operability without user configuration required) into the DDS controller **124**. For example, the DMCs **126** may include Ethernet input connectors or adapters (e.g., RJ-45) and optical fiber output connectors or adapters (e.g., LC, SC, ST, MTP).

With continuing reference to FIG. 5, the DDS controller **124** (via the DMCs **126**) in this embodiment is configured to convert downlink electrical digital signals (or downlink electrical digital data services signals) **128D** over digital line cables **129** from the DDS switch **127** into downlink optical digital signals (or downlink optical digital data services signals) **130D** that can be communicated over downlink optical fiber **135D** to RAUs **14**. The DDS controller **124** (via the DMCs **126**) is also configured to receive uplink optical digital signals **130U** from the RAUs **14** via the uplink optical fiber **135U** and convert the uplink optical digital signals **130U** into uplink electrical digital signals **128U** to be communicated to the DDS switch **127**. In this manner, the digital data services

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can be provided over optical fiber as part of the optical fiber-based distributed antenna system 120 to provide digital data services in addition to RF communication services. Client devices located at the RAUs 14 can access these digital data services and/or RF communications services depending on their configuration. Exemplary digital data services include WLAN, Ethernet, WLAN, WiMax, WiFi, Digital Subscriber Line (DSL), and LTE, etc. Ethernet standards could be supported, including but not limited to 100 Megabits per second (Mbps) (i.e., fast Ethernet) or Gigabit (Gb) Ethernet, or ten Gigabit (10G) Ethernet.

With continuing reference to FIG. 5, in this embodiment, downlink and uplink optical fibers 132D, 132U are provided in a fiber optic cable 134 that is interfaced to the ICU 85. The ICU 85 provides a common point in which the downlink and uplink optical fibers 132D, 132U carrying digital optical signals can be bundled with the downlink and uplink optical fibers 16U, 16D carrying optical RF communications signals. One or more of the fiber optic cables 134, also referenced herein as array cables 134, can be provided containing the downlink and uplink optical fibers 135D, 135U for RF communications services and digital data services to be routed and provided to the RAUs 14. Any combination of services or types of optical fibers can be provided in the array cable 134. For example, the array cable 134 may include single mode and/or multi-mode optical fibers for RF communication services and/or digital data services.

Examples of ICUs that may be provided in the optical fiber-based distributed antenna system 120 to distribute both downlink and uplink optical fibers 135D, 135U for RF communications services and digital data services are described in U.S. patent application Ser. No. 12/466,514, filed on May 15, 2009, entitled "Power Distribution Devices, Systems, and Methods For Radio-Over-Fiber (RoF) Distributed Communication," and U.S. Provisional Application Ser. No. 61/330,385 filed on May 2, 2010, entitled "Power Distribution in Optical Fiber-Based Distributed Communications Systems Providing Digital Data and Radio Frequency (RF) Communications Services, and Related Components and Methods," both of which are incorporated herein by reference in their entireties.

With continuing reference to FIG. 5, some RAUs 14 can be connected to access units (AUs) 138, which may be access points (APs) or other devices supporting digital data services. AUs 138 can also be connected directly to the HEU 12. AUs 138 are illustrated, but the AUs 138 could be any other device supporting digital data services. In the example of AUs, the AUs 138 provide access to the digital data services provided by the DDS switch 127. This is because the downlink and uplink optical fibers 135D, 135U carrying downlink and uplink optical digital signals 130D, 130U converted from downlink and uplink electrical digital signals 128D, 128U from the DDS switch 127 are provided to the AUs 138 via the array cables 134 and RAUs 14. Digital data client devices can access the AUs 138 to access digital data services provided through the DDS switch 127. The AUs 138 may also each include an antenna 140 to provide wireless access to digital data services provided through the DDS switch 127.

As will be described in more detail below, providing RF communications services and digital data services involves providing RF communications modules and DDS modules in the RAUs 14 and/or AUs 138 in the example of FIG. 5. These modules are power-consuming modules that require power to operate. Power distributed to the RAUs can also be used to provide access to power for DDS modules, as opposed to providing separate power sources for DDS modules and RF communications modules. For example, power distributed to

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the RAUs 14 in FIG. 5 by or through the ICUs 85 can also be used to provide power to the AUs 138 located at the RAUs 14 in the optical fiber-based distributed antenna system 120. In this regard, the ICUs 85 may be configured to provide power for both RAUs 14 and the AUs 138 over an electrical power line 142, as illustrated in FIG. 5. As will also be described in more detail below, the RAUs 14 and/or AUs 138 may also be configured with powered ports to provide power to external client devices connected to the powered ports, such as IEEE 802.3af Power-over-Ethernet (PoE) compatible devices as an example. However, referring to FIG. 5 as an example, the power made available to the RAUs 14 and AUs 138 may not be sufficient to power all of the modules provided and external devices connected to the RAUs 14 and AUs 138.

In this regard, embodiments disclosed below include power management for an RAU(s) in a distributed antenna system, and related devices, systems, methods, and computer-readable media. Power can be managed for an RAU configured to power modules and devices that may require more power to operate than power available to the RAU. For example, the RAU may be configured to include power-consuming RAU modules to provide distributed antenna system-related services. As another example, the RAU may be configured to provide power through powered ports in the RAU to external power-consuming devices. Depending on the configuration of the RAU, the power-consuming RAU modules and/or external power-consuming devices may demand more power than is available at the RAU. In this instance, the power available at the RAU can be distributed to the power-consuming modules and devices based on the priority of services desired to be provided by the RAU.

FIG. 6 is a schematic diagram of an exemplary RAU 14 configured with power-consuming components. The RAU 14 is configured to receive power over a power line 150 routed to the RAU 14 from either a local power source or a remote power source to make power available for power-consuming components associated with the RAU 14. As a non-limiting example, the power line 150 may provide a voltage of between forty-eight (48) and sixty (60) Volts at a power rating of between eighty (80) to one hundred (100) Watts. In this example, the RAU 14 includes an RF communications module 152 for providing RF communications services. The RF communications module 152 requires power to operate in this embodiment and receives power from the power line 150. Power may be routed from the power line 150 directly to the RF communications module 152, or indirectly from another module. The RF communications module 152 may include any of the previously referenced components to provide RF communications services, including O/E and E/O conversion.

With continuing reference to FIG. 6, the RAU 14 may also include a DDS module 154 to provide media conversion (e.g., O/E and E/O conversions) and route digital data services received from the DDS switch 127 in FIG. 5 to externally connected power-consuming devices (PDs) 156(1)-156(Q) configured to receive digital data services. Power may be routed from the power line 150 to the DDS module 154 through the RF communications module 152 as one example. is provided to route power from the power line 150 to the DDS module 154. With reference to FIG. 6, the digital data services are routed by the DDS module 154 through communications ports 158(1)-158(Q) provided in the RAU 14. As a non-limiting example, the communications ports 158(1)-158(Q) may be RJ-45 connectors. The communications ports 158(1)-158(Q) may be powered, meaning that a portion of the power from the power line 150 is provided to the powered communications ports 158(1)-158(Q). In this manner, PDs 156(1)-

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156(Q) configured to receive power through a powered communications port 158 can be powered from power provided to the RAU 14 when connected to the powered communications port 158. In this manner, a separate power source is not required to power the PDs 156(1)-156(Q). For example, the DDS module 154 may be configured to route power to the powered communications ports 158(1)-158(Q) as described in the PoE standard.

With continuing reference to FIG. 6, one or more remote expansion units (RXUs) 160(1)-160(Z) may also be connected to the RAU 14. The RXUs 160(1)-160(Z) can be provided to provide additional RF communications services through the RAU 14, but remotely from the RAU 14. For example, if additional RF communications bands are needed and there are no additional bands available in a distributed antenna system, the RF communications bands of an existing RAU 14 can be expanded without additional communications bands by providing the RXUs 160(1)-160(Z). The RXUs 160(1)-160(Z) are connected to the distributed antenna system through the RAU 14. The RXUs 160(1)-160(Z) can include the same or similar components provided in the RF communications module 152 to receive downlink RF communications signals 162D and to provide received uplink RF communications signals 162U from client devices to the distributed antenna system through the RAU 14. The RXUs 160(1)-160(Z) are also power-consuming modules, and thus in this embodiment, power from the power line 150 is routed by the RAU 14 to the RXUs 160(1)-160(Z) over a power line 164.

The power provided on the power line 150 in FIG. 6 may not be sufficient to provide power for the modules 152, 154, 160(1)-160(Z) and external PDs 156(1)-156(Q) provided in the RAU 14. For example, eighty (80) Watts of power may be provided on the power line 150 in FIG. 6. However, the RF communications module 152 may consume thirty (30) Watts of power, the RXUs 160(1)-160(Z) may consume twenty (20) Watts of power, and the DDS module 154 may consume five (5) Watts of power. This is a total of fifty-five (55) Watts. In this example, twenty-five (25) Watts are available to be shared among the powered communications ports 158(1)-158(Q). However, the PDs 156(1)-156(Q) may be configured to require more power than twenty-five (25) Watts. For example, if the PDs 156(1)-156(Q) are configured according to the PoE standard, power source equipment (PSE) provided in the RAU 14 to provide power to the powered communications ports 158(1)-158(Q) may be required to provide up to 15.4 Watts of power to each powered communications port 158(1)-158(Q). In this example, if more than one powered communications port 158(1)-158(Q) is provided, there will not be sufficient power to power each of the powered communications port 158(1)-158(Q) at 30 Watts (i.e., a PoE Class 4 device).

Thus, to ensure proper operation of the maximum power consuming modules 152, 154, 160(1)-160(Z) possible in an RAU 14, less power could be provided to the powered communications port 158(1)-158(Q) or only one powered communications port 158(1)-158(Q) could be enabled with power. However, if one of the other modules 152, 154, 160(1)-160(Z) was not present, sufficient power may be available to be provided to each of the powered communications ports 158(1)-158(Q) provided. Further, if a PD 156 connected to a powered communication port 158 is a lower class device that does not require 30 Watts of power, there may be sufficient power available to power the PDs 156(1)-156(Q) connected to each of the powered communications ports 158(1)-158(Q).

In this regard, FIG. 7 is an exemplary priority scheme for a power management scheme to provide sufficient power to

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power-consuming modules and PDs that may be powered by an RAU 14. In this example, RF communications services have been assigned higher priority than digital data services and powered ports. Thus, in this example, the available power on the power line 150 will be made available to the RF communications module 152. If more power is available from the power line 150 after power has been budgeted for the RF communications module 152, the remaining power is made available to the RXUs 160(1)-160(Z) to provide expansion RF communications services. If more power is available from the power line 150 after power has been budgeted for the RF communications module 152 and the RXUs 160(1)-160(Z), the remaining power is made available to the DDS module 154 to provide digital data services. If more power is available from the power line 150 after power has been budgeted for the RF communications module 152, the RXUs 160(1)-160(Z), and the DDS module 154, the remaining power is made available to the powered communications ports 158(1)-158(Q) to provide power to the PDs 156(1)-156(Q). Note that the priority scheme in FIG. 7 is exemplary and any other priority scheme desired could be implemented in a power management scheme.

With continuing reference to FIG. 7, power is budgeted such that power is made available sufficient to power the PD 158(1) connected to the first powered communications port 158(1). If more power is available from the power line 150 after power has been budgeted for the RF communications module 152, the RXUs 160(1)-160(Z), the DDS module 154, and the PD 158(1) connected to the first powered communications port 158(1), power is made available to the other powered communications ports 158(2)-158(Q) until sufficient power is not available to power the PDs 156(2)-156(Q) connected to the additional powered communications ports 158(2)-158(Q). If the remaining power budget is not sufficient to power the PDs 156 connected to any powered communications ports 158, these powered communications ports 158 can be disabled. Further, if any of the modules 152, 154, 160(1)-160(Z) are not present or are removed for a particular RAU 14, the available power budget for the powered communications ports 158(1)-158(Q) may increase thereby allowing previously disabled powered communications ports 158(1)-158(Q) to be enabled.

FIG. 8 is a schematic diagram of an exemplary embodiment of components that can be provided in the RAU 14 of FIG. 6 to provide for remote power management of power provided to the power-consuming modules 152, 154, 160(1)-160(Z) and the externally connected PDs 156(1)-156(Q). The discussion of remote power management of the RAU 14 in FIG. 8 will be described in conjunction with the flowcharts in FIGS. 9-11. FIG. 9 is a flowchart illustrating an exemplary remote power management process provided by the HEC 44 in FIG. 2 to perform remote power management at an RAU 14. FIG. 10 is a flowchart illustrating an exemplary power management process provided by an RAU 14 to manage power at the RAU 14 at initialization and when configuration changes are made to the RAU 14. FIG. 11 is a flowchart illustrating an exemplary power management process provided by an RAU 14 to manage power provided to PDs 156(1)-156(Q) connected to powered communications ports 158(1)-158(Q) provided in a RAU 14.

With reference to FIG. 8, the RAU 14 includes power source equipment (PSE) 170. The PSE 170 is configured to direct power from a power line 171, which receives power from the power line 150 through the RF communications module 152, to PDs 156(1)-156(Q) connected to the powered communications ports 158(1)-158(Q). A controller 176 provided in the DDS module 154 coupled to memory 178 is

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configured to provide power management functions according to an available power budget received from the HEC 44, as will be described in more detail below with regard to FIGS. 9-11. By receiving the available power budget that can be provided from the power line 150 by the PSE 170 to power the PDs 156(1)-156(Q) connected to the powered communications ports 158(1)-158(Q), the PSE 170 can manage directing power to the PDs 156(1)-156(Q) connected to the powered communications ports 158(1)-158(Q) without depriving the other modules 152, 154, 160(1)-160(Z) present in the RAU 14 from receiving sufficient power to operate.

As illustrated in FIG. 9, to provide power management at the RAUs 14, the HEC 44 in the HEU 12 is employed. For each RAU 14, the HEC 44 receives a configuration of which power-consuming modules 152, 154, 160(1)-160(Z) are present in the RAU 14 (block 180 in FIG. 9). The HEC 44 communicates with the RAUs 14 using digital communications communicated over the same communications links as provided to carry RF communications signals. More information on providing a digital communication and control system in a distributed antenna system is described in U.S. Provisional Application No. 61/230,472 filed on Jul. 31, 2009 entitled "Optical Fiber-Based Distributed Antenna Systems, Components, and Related Methods for Monitoring the Status Thereof," which is incorporated herein by reference in its entirety. The HEC 44 determines the power required for the modules 152, 154, 160(1)-160(Z) present in the RAU 14 by consulting the memory unit 46 (block 182 in FIG. 9). For example, the memory unit 46 may be programmed with the power consumption rates correlated to different types of modules 152, 154, 160(1)-160(Z) that can be looked up in the memory unit 46 by the HEC 44.

As will be discussed below with regard to FIG. 10, the RAU 14 may provide the particular hardware and/or software elements, and/or versions of those elements of the modules 152, 154, 160(1)-160(Z) present in the RAU 14 that can be used by the HEC 44 to determine the power requirements of the modules 152, 154, 160(1)-160(Z). The HEC 44 then determines the available power budget for the RAU 14 to provide power to any PDs 156(1)-156(Q) connected to the powered communications ports 158(1)-158(Q) based on the total power provided to the RAU 14 minus the power required to sufficiently power the modules 152, 154, 160(1)-160(Z) present in the RAU 14 (block 184 in FIG. 9). The total power available to the RAU 14 can be programmed into the memory unit 46, including by a user through a graphical user interface (GUI) hosted by the HEU 12, or by other configuration. The process continues on a repetitive basis for each of the RAUs 14 configured for the HEU 12. By performing the process in FIG. 9, the RAUs 14 receive the available power budget that can be allocated to provide power to the PDs 156(1)-156(Q) connected to the powered communications ports 158(1)-158(Q) in the RAUs 14.

The RAU 14 also performs a process to provide power management. The process may be performed by the controller 176 in the DDS module 154 illustrated in FIG. 8. FIG. 10 is a flowchart illustrating an exemplary power management process provided by an RAU 14 to manage power at the RAU 14 at initialization and when configuration changes are made to the RAU 14. The RAU 14 checks the configuration of the modules 152, 154, 160(1)-160(Z) present in the RAU 14 to determine if the configuration of the RAU 14 has changed (block 190). For example, a module 152, 154, 160(1)-160(Z) may have been added or removed from the RAU since the configuration was last determined and provided to the HEC 44. If the configuration of the RAU 14 has changed (block 192), the RAU 14 obtains the module type and the hardware

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and software versions of the modules 152, 154, 160(1)-160(Z) (block 194). The RAU 14 then sends the module type and the hardware and software versions of the modules 152, 154, 160(1)-160(Z) to the HEC 44 (block 196). This information is received by the HEC 44 in block 180 in FIG. 9, previously described above.

With continuing reference to FIG. 10, the controller 176 in the RAU 14 waits for the new available power budget for the RAU 14 provided by the HEC 44 according to the process in FIG. 9 (block 198). When received (block 200), the controller 176 determines if the DDS module 154 is installed in the RAU 14 (block 202). If not, the controller 176 determines if the RXU modules 160(1)-160(Z) are installed (block 204). If not, the process repeats. If the RXU modules 160(1)-160(Z) are installed (block 204), the controller 176 determines if the RXU modules 160(1)-160(Z) are switched on (block 206). If so, the process repeats. If not, the controller 176 instructs the RF communications module 152 to switch on the RXU modules 160(1)-160(Z) (block 208) and the process repeats.

With continuing reference to FIG. 10, if the controller 176 determines that the DDS module 154 is installed (block 202), this means that digital data services are provided by the RAU 14. In this instance, the powered communications ports 158 are present to allow PDs 156(1)-156(Q) to connect to the powered communications ports 158(1)-158(Q) to receive digital data services supported by the DDS module 154. In this regard, the controller 176 directs the PSE 170 to send the available power budget received from the HEC 44 to the powered communications ports 158(1)-158(Q) in the RAU 14 (block 210). The PDs 156(1)-156(Q) connected to the powered communications ports 158(1)-158(Q) may be enabled or disabled depending on the available power budget and the power requirements of the PDs 156(1)-156(Q) connected to the powered communications ports 158(1)-158(Q). The controller 176 waits for a status of the PDs 156(1)-156(Q) connected to the powered communications ports 158 (block 212). When the status of the PDs 156(1)-156(Q) connected to the powered communications ports 158(1)-158(Q) is received (block 214), the status is sent by the controller 176 to the HEC 44 (block 216). The controller 176 then powers on the RXU modules 160(1)-160(Z) if present and not already switched on (blocks 204, 206, 208).

FIG. 11 is a flowchart illustrating an exemplary power management process provided by an RAU 14 to manage power provided to PDs 156(1)-156(Q) when the status of the powered communications ports 158(1)-158(Q) provided in an RAU 14 changed (i.e., connected or disconnected). If the status of any powered communications port 158(1)-158(Q) has increased power requirements, such as by a new connection or a connection with a PD 156 requiring more power, other powered communications ports 158(1)-158(Q) may be required to be disabled to remain within the available power budget. If the status of any powered communications ports 158(1)-158(Q) has decreased power requirements, other powered communications ports 158(1)-158(Q) may be able to be enabled and still remain within the available power budget.

With reference to FIG. 11, the controller 176 determines if the configuration of the RAU 14 has changed (block 220). If changed (block 222), the controller 176 determines if the change is due to a change in status of a powered communications ports 158(1)-158(Q) in the RAU 14 (block 224). In this example, power is managed for two (2) powered communications ports 158(1), 158(2), but any number could be managed. If a powered communications port 158(1)-158(Q) has not changed, this means that the available power budget to provide power to the PDs 156(1)-156(Q) has changed since at

least one module **152**, **154**, **160(1)**-**160(Z)** has either been removed or added to the RAU **14**. In this instance, the controller **176** determines if a PD **156(1)** is connected to the first powered communications port **158(1)** that is unpowered (block **226**). If so, the controller **176** determines if the available power budget is sufficient to provide power to the PD **156(1)** connected to the first powered communications port **158(1)** (block **228**). If so, the controller **176** directs the PSE **170** to provide power to the first powered communications port **158(1)** (block **230**). If not, the controller **176** checks the status of the second powered communications port **158(2)** (block **232**).

If the controller **176** determines that the first powered communications port **158(1)** is not powered (block **226**), the controller **176** determines if a PD **156(2)** is connected to a second powered communications port **158(2)** that is unpowered (block **232**). If so, the controller **176** determines if the available power budget is sufficient to provide power to the PD **156(2)** connected to the second powered communications port **158(2)** (block **234**). If so, the controller **176** directs the PSE **170** to provide power to the second powered communications port **158(2)** (block **236**). If not, the controller **176** does not change the power configuration of the second powered communications port **158(2)**. Thus, the controller **176** manages power to by enabling a first powered communications port **158(1)** if available power budget is present, and then enabling a second powered communications port **158(2)** if available power budget is available after providing power to the first powered communications port **158(1)**. When the available power budget changes for the RAU **14**, the enabling or disabling of the powered communications ports **158(1)**, **158(2)** is re-evaluated based on the available power budget.

If the status of the powered communications ports **158(1)**, **158(2)** has changed (block **224**), the current power settings of the powered communications ports **158(1)**, **158(2)** is also re-evaluated. In this regard, if the first powered communications port **158(1)** is connected (block **238**), the controller **176** obtains the class of the PD **156(1)** connected to the powered communications port **158(1)** from the PSE **170** (block **240**). The controller **176** determines if the available power budget is sufficient to power the PD **156(1)** at its class rating (block **242**). If so, the controller **176** directs the PSE **170** to enable the powered communications port **158(1)** to provide power to the PD **156(1)** connected to the powered communications port **158(1)** (block **244**). For example, if the available power budget is 16 Watts, a PoE Class 3 PD **156(1)** rated at 15.4 Watts connected to a powered communications port **158(1)** can be powered, and thus the powered communications port **158(1)** is enabled. However, if a PoE Class 4 PD **156(1)** rated at 30 Watts or less is connected to a powered communications port **158(1)**, the powered communications port **158(1)** is disabled since the available power budget is less than 30 Watts.

The available power budget for the RAU **14** is updated by the controller **176** in memory **178** based on the class of the PD **156(1)** connected to the powered communications port **158(1)** (block **246**) so that power is not directed to the second powered communications port **158(2)** if there is not sufficient power budget remaining. If the available power budget is not sufficient to power the PD **156(1)** connected to the powered communications port **158(1)** (block **242**), the controller **176** disables the powered communications port **158(1)** so that power is not made available by the PSE **170** to the powered communications port **158(1)** (block **248**).

If a PD **156(1)** is not connected to the first powered communications port **158(1)** (block **238**), the controller **176** determines if the first powered communications port **158(1)** is disconnected (block **249**). If not, the controller **176** deter-

mines if a PD **156(2)** is connected to the second powered communications port **158(2)** (block **250**). If so, the controller **176** obtains the class of the PD **156(2)** connected to the powered communications port **158(2)** from the PSE **170** (block **252**). The controller **176** determines if the available power budget is sufficient to power the PD **156(2)** at its class rating (block **254**). If so, the controller **176** directs the PSE **170** to enable the powered communications port **158(2)** to provide power to the PD **156(2)** connected to the powered communications port **158(2)** (block **256**). The available power budget for the RAU **14** is updated by the controller **176** in memory **178** based on the class of the PD **156(2)** connected to the powered communications port **158(2)** (block **246**) so that power is not directed to the other powered communications port **158(1)** if there is not sufficient power budget remaining. If the available power budget is not sufficient to power the PD **156(2)** connected to the powered communications port **158(2)** (block **254**), the controller **176** disables the powered communications port **158(2)** so that power is not made available by the PSE **170** to the powered communications port **158(2)** (block **258**).

FIG. **12** is a more detailed diagram of one embodiment of the DDS module **154** in FIG. **8** that can be provided in an RAU **14** to provide digital data services to the PDs **156(1)**-**156(Q)** connected to the powered communications ports **158(1)**-**158(Q)** and to provide power management for the powered communications ports **158(1)**-**158(Q)**, as described above. As illustrated in FIG. **12**, the DDS module **174** includes a transmit optical sub-assembly (TOSA) **260** and a receive optical sub-assembly (ROSA) **262** to convert downlink optical digital signals **130D** from the downlink optical fiber **135D** to downlink electrical digital signals and convert uplink electrical digital signals to uplink optical digital signals **130U**. A DDS switch **264** is provided to switch digital data services to the powered communications ports **158(1)**-**158(Q)**. The controller **176** is provided as a PoE PSE controller to manage power provided to the powered communications ports **158(1)**-**158(Q)**. A power interface **266** is provided to receive power from the power line **171** from the RF communications module **152**. Switches **268** and light emitting diodes (LEDs) **270** are provided to allow configuration settings and to provide the status of the DDS module **174**, respectively.

FIG. **13** is a schematic diagram representation of an exemplary electronic device **280** in the exemplary form of an exemplary computer system **282** adapted to execute instructions from an exemplary computer-readable medium to perform the power management functions. The electronic device **280** may be the DDS module **154**, but could be any other module or device provided in the RAU **14**. The electronic device **280** could be provided separately from the other modules **152**, **154**, **160(1)**-**160(Z)** that can be configured for the RAU **14**. In this regard, the electronic device **280** may comprise the computer system **282** within which a set of instructions for causing the electronic device **280** to perform any one or more of the methodologies discussed herein may be executed. The electronic device **280** may be connected (e.g., networked) to other machines in a LAN, an intranet, an extranet, or the Internet. The electronic device **280** may operate in a client-server network environment, or as a peer machine in a peer-to-peer (or distributed) network environment. While only a single device is illustrated, the term "device" shall also be taken to include any collection of devices that individually or jointly execute a set (or multiple sets) of instructions to perform any one or more of the methodologies discussed herein. The electronic device **280** may be a server, a personal computer, a desktop computer, a laptop computer, a personal

digital assistant (PDA), a computing pad, a mobile device, or any other device, and may represent, for example, a server or a user's computer.

The exemplary computer system **282** includes a processing device or processor **284**, a main memory **286** (e.g., read-only memory (ROM), flash memory, dynamic random access memory (DRAM) such as synchronous DRAM (SDRAM), etc.), and a static memory **288** (e.g., flash memory, static random access memory (SRAM), etc.), which may communicate with each other via a bus **290**. Alternatively, the processing device **284** may be connected to the main memory **286** and/or the static memory **288** directly or via some other connectivity means. The processing device **284** may be the controller **176**, and the main memory **286** or static memory **288** may be the memory **178**.

The processing device **284** represents one or more general-purpose processing devices such as a microprocessor, central processing unit, or the like. More particularly, the processing device **284** may be a complex instruction set computing (CISC) microprocessor, a reduced instruction set computing (RISC) microprocessor, a very long instruction word (VLIW) microprocessor, a processor implementing other instruction sets, or processors implementing a combination of instruction sets. The processing device **284** is configured to execute processing logic in instructions **292** for performing the operations and steps discussed herein.

The computer system **282** may further include a network interface device **294**. The computer system **282** also may or may not include an input **296** to receive input and selections to be communicated to the processing device **284** when executing instructions. The computer system **282** also may or may not include an output **298**, including but not limited to a display, a video display unit (e.g., a liquid crystal display (LCD) or a cathode ray tube (CRT)), an alphanumeric input device (e.g., a keyboard), and/or a cursor control device (e.g., a mouse).

The computer system **282** may or may not include a data storage device that includes instructions **300** stored in a computer-readable medium **302** embodying any one or more of the RAU **14** power management methodologies or functions described herein. The instructions **300** may also reside, completely or at least partially, within the main memory **286** and/or within the processing device **284** during execution thereof by the computer system **282**, the main memory **286** and the processing device **284** also constituting computer-readable media. The instructions **300** may further be transmitted or received over a network **304** via the network interface device **294**.

While the computer-readable medium **302** is shown in an exemplary embodiment to be a single medium, the term "computer-readable medium" should be taken to include a single medium or multiple media (e.g., a centralized or distributed database, and/or associated caches and servers) that store the one or more sets of instructions. The term "computer-readable medium" shall also be taken to include any medium that is capable of storing, encoding or carrying a set of instructions for execution by the processor and that cause the processor to perform any one or more of the methodologies of the embodiments disclosed herein. The term "computer-readable medium" shall accordingly be taken to include, but not be limited to, solid-state memories, optical and magnetic media, and carrier wave signals.

The DDS modules disclosed herein may be provided any type of digital data services. The powered communications ports provided in the RAU may be provided to meet any power standard. In the example of PoE, IEEE 802.3at specifies that link layer discovery protocol (LLDP) may be used

and supported by the components described herein, including the controllers and power management components in the RAUs. LLDP allows exchange of data with PDs to determine the power rating of the PD. Also, more precise information regarding power requirements can only be exchanged using LLDP for media endpoint devices, such as LLDP-MED, according to TIA-1057). LLDP-MED allows requesting of power by PDs between 0 and 102.3 Watts in 0.1 Watt steps. LLDP and LLDP-MED are layer 2 protocols, which require a means to receive and transmit those Ethernet packets from and to PDs. This can be performed by the controllers disclosed herein and provided in the RAUs having an Ethernet media access controller connected to an Ethernet switch inside the media converter. Alternatively, power ratings for a PD could be provided manually or programmed into the RAUs by an operator accessing the RAUs in the distributed antenna system.

The embodiments disclosed herein include various steps. The steps of the embodiments disclosed herein may be performed by hardware components or may be embodied in machine-executable instructions, which may be used to cause a general-purpose or special-purpose processor programmed with the instructions to perform the steps. Alternatively, the steps may be performed by a combination of hardware and software.

The embodiments disclosed herein may be provided as a computer program product, or software, that may include a machine-readable medium (or computer-readable medium) having stored thereon instructions, which may be used to program a computer system (or other electronic devices) to perform a process according to the embodiments disclosed herein. A machine-readable medium includes any mechanism for storing or transmitting information in a form readable by a machine (e.g., a computer). For example, a machine-readable medium includes a machine-readable storage medium (e.g., read only memory ("ROM"), random access memory ("RAM"), magnetic disk storage media, optical storage media, flash memory devices, etc.), a machine-readable transmission medium (electrical, optical, acoustical or other form of propagated signals (e.g., carrier waves, infrared signals, digital signals, etc.), etc.

Unless specifically stated otherwise as apparent from the previous discussion, it is appreciated that throughout the description, discussions utilizing terms such as "processing," "computing," "determining," "displaying," or the like, refer to the action and processes of a computer system, or similar electronic computing device, that manipulates and transforms data represented as physical (electronic) quantities within the computer system's registers and memories into other data similarly represented as physical quantities within the computer system memories or registers or other such information storage, transmission, or display devices.

The algorithms and displays presented herein are not inherently related to any particular computer or other apparatus. Various general purpose systems may be used with programs in accordance with the teachings herein, or it may prove convenient to construct more specialized apparatus to perform the required method steps. The required structure for a variety of these systems will appear from the description above. In addition, the embodiments described herein are not described with reference to any particular programming language. It will be appreciated that a variety of programming languages may be used to implement the teachings of the embodiments as described herein.

Those of skill in the art would further appreciate that the various illustrative logical blocks, modules, circuits, and algorithms described in connection with the embodiments

disclosed herein may be implemented as electronic hardware, instructions stored in memory or in another computer-readable medium and executed by a processor or other processing device, or combinations of both. The components of the distributed antenna systems described herein may be employed in any circuit, hardware component, integrated circuit (IC), or IC chip, as examples. Memory disclosed herein may be any type and size of memory and may be configured to store any type of information desired. To clearly illustrate this interchangeability, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. How such functionality is implemented depends upon the particular application, design choices, and/or design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present invention.

The various illustrative logical blocks, modules, and circuits described in connection with the embodiments disclosed herein may be implemented or performed with a processor, a Digital Signal Processor (DSP), an Application Specific Integrated Circuit (ASIC), a Field Programmable Gate Array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A controller may be a processor. A processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

The embodiments disclosed herein may be embodied in hardware and in instructions that are stored in hardware, and may reside, for example, in Random Access Memory (RAM), flash memory, Read Only Memory (ROM), Electrically Programmable ROM (EPROM), Electrically Erasable Programmable ROM (EEPROM), registers, a hard disk, a removable disk, a CD-ROM, or any other form of computer-readable medium known in the art. An exemplary storage medium is coupled to the processor such that the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a remote station. In the alternative, the processor and the storage medium may reside as discrete components in a remote station, base station, or server.

It is also noted that the operational steps described in any of the exemplary embodiments herein are described to provide examples and discussion. The operations described may be performed in numerous different sequences other than the illustrated sequences. Furthermore, operations described in a single operational step may actually be performed in a number of different steps. Additionally, one or more operational steps discussed in the exemplary embodiments may be combined. It is to be understood that the operational steps illustrated in the flow chart diagrams may be subject to numerous different modifications as will be readily apparent to one of skill in the art. Those of skill in the art would also understand that information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description may be represented by voltages, cur-

rents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

Further, as used herein, it is intended that the terms “fiber optic cables” and/or “optical fibers” include all types of single mode and multi-mode light waveguides, including one or more optical fibers that may be upcoated, colored, buffered, ribbonized and/or have other organizing or protective structures in a cable such as one or more tubes, strength members, jackets or the like. The optical fibers disclosed herein can be single mode or multi-mode optical fibers. Likewise, other types of suitable optical fibers include bend-insensitive optical fibers, or any other expedient of a medium for transmitting light signals. An example of a bend-insensitive, or bend resistant, optical fiber is ClearCurve® Multimode fiber commercially available from Corning Incorporated. Suitable fibers of this type are disclosed, for example, in U.S. Patent Application Publication Nos. 2008/0166094 and 2009/0169163, the disclosures of which are incorporated herein by reference in their entireties.

Many modifications and other embodiments of the embodiments set forth herein will come to mind to one skilled in the art to which the embodiments pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings.

What is claimed is:

1. A wireless communication system, comprising:

- a plurality of remote antenna units (RAU), each RAU comprising a radio frequency (RF) communications module having at least one antenna configured to provide RF communications services to a coverage area, wherein at least one of the RAUs is configured to provide power to at least one external power-consuming device connected to at least one powered port; and
- a head-end unit (HEU) comprising a remote controller communicatively coupled to the plurality of RAUs, wherein the remote controller is configured to:
 - communicate with the at least one RAU to determine an available power budget for the at least one powered port; and
 - communicate the available power budget for the at least one powered port in the at least one RAU to the at least one RAU.

2. The wireless system of claim 1, wherein the at least one RAU is configured to transmit uplink optical communications signals to the HEU, and wherein the HEU comprises at least one interface module configured to receive and process downlink communications signals.

3. The wireless system of claim 2, wherein the HEU comprises at least one optical interface module configured to convert the downlink communications signals into downlink optical signals, and wherein the HEU is optically coupled to the at least one RAU.

4. The wireless system of claim 3, wherein the remote controller is configured to receive a type of at least one power-consuming RAU module present in the at least one RAU from the at least one RAU.

5. The wireless system of claim 4, wherein the remote controller is configured to determine the available power budget for the at least one powered port based on power required for the at least one power-consuming RAU module present in the at least one RAU.

6. The wireless system of claim 5, wherein the remote controller is further configured to look up in memory coupled to the remote controller, the power required for the at least one power-consuming RAU module present in the at least one RAU.

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7. The wireless system of claim 5, wherein the remote controller is configured to determine the power required for the at least one power-consuming RAU module present in the at least one RAU based on a type of the RAU module.

8. The wireless system of claim 2, wherein the remote controller is further configured to receive a power status of the at least one powered port from the at least one RAU.

9. A method of managing power consumed at a remote antenna unit (RAU) in a wireless communication system comprising a plurality of RAUs, the method comprising:

receiving an available power budget for at least one powered port configured to provide power to at least one external power-consuming device connected to the at least one powered port based on power required by at least one power-consuming RAU module;

enabling power for the at least one powered port if the available power budget is sufficient to power the at least one external power-consuming device connected to the at least one powered port; and

disabling the at least one powered port if the available power budget is not sufficient to power the at least one external power-consuming device connected to the at least one powered port.

10. The method of claim 9, wherein the at least one powered port is comprised of a plurality of powered ports, the method further comprising disabling at least one first port among the plurality of powered ports if the available power budget is only sufficient to power the at least one external power-consuming device connected to at least one second port among the plurality of powered ports.

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11. The method of claim 10, further comprising determining if a status of the at least one powered port has changed, and determining a device class of the at least one external power-consuming device connected to the at least one powered port.

12. A method of managing power consumed at a remote antenna unit (RAU) in a wireless communication system, the method comprising:

receiving an available power budget for at least one powered port configured to provide power to at least one external power-consuming device connected to the at least one powered port based on power required by at least one power-consuming RAU module;

determining a device class of the at least one external power-consuming device connected to the at least one powered port;

enabling power for the at least one powered port if the available power budget is sufficient to power the at least one external power-consuming device of the device class connected to the at least one powered port; and

disabling power for the at least one powered port if the available power budget is not sufficient to power the at least one external power-consuming device of the device class.

13. The method of claim 12, wherein the RAU is configured to communicate optical uplink communications signals, to receive optical downlink communications signals, and to receive RF uplink communications signals.

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